LOCAL COMPREHENSIVE PLAN EVALUATION FOR SUSTAINABLE STORMWATER MANAGEMENT AND FLOOD MITIGATION

A Dissertation

by

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ABSTRACT

This study begins with a systematic evaluation of the quality of 76 local plans within the Chesapeake Bay watershed in order to better understand whether local jurisdictions have thoroughly integrated the concepts of sustainable stormwater management into their comprehensive plans.

The study first examines which specific factors may contribute to explaining the variation in plan quality. Second, this study explores the impact of planning capacity on mean and peak annual runoff. By employing multivariate regression analyses, the degree of association of planning factors and other contextual variables with mean and peak annual runoff was investigated for 75 sub-basins.

The Chesapeake Bay watershed was chosen for the investigation because the bay has been severely polluted by urban and suburban stormwater runoff resulting from the rapid growth of its nearby jurisdictions. The watershed covers approximately 166,000 km^2 and encompasses seven states in the Mid-Atlantic region.

The study results show that most local jurisdictions are likely to have relatively weak comprehensive plans integrating the principles of sustainable stormwater management, with an average plan score of 22.55 out of 50. The results of multiple regression analyses further identify that an impervious surface and a plan’s adopted year positively impact plan quality, while previous flooding and storm surge events negatively influence the quality of local plans. This study also demonstrates that sub-basins that were included in jurisdictions with relatively high plan quality scores tended

to generate higher volumes of peak annual runoff. Whereas, sub-basins included in jurisdictions with more planners are likely to produce less mean annual runoff. In addition, the results suggest that surface runoff can be significantly affected by impervious surface, average basins slope, basin shape, precipitation, historical flash flood events, natural drainage density, floodplain, and soil characteristics.

This study concludes with policy implications and recommendations to increase awareness and understanding of sustainable stormwater management concepts as well as how local planning efforts and capacities may effectively contribute to the mitigation of surface runoff and flash flooding.

DEDICATION

To my family

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NOMENCLATURE

APA	American Planning Association
BMP	Best Management Practices
CAI	Climatologically-Aid Interpolation
CBF	Chesapeake Bay Foundation
CBW	Chesapeake Bay Watershed
CRS	Community Rating Systems
CSQA	California Stormwater Quality Association
CWA	Clean Water Act
DEH	Department of Environmental Health
DEHP	Department of Environment and Heritage Protection
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Map
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GME	Geospatial Modelling Environment
IPCC	Intergovernmental Panel on Climate Change
LEED	Leadership in Energy and Environmental Design
LEED-ND	Leadership in Energy and Environmental Design for Neighborhood Development

LID	Low Impact Development
LULC	Land Use Land Cover
MAR	Mean Annual Runoff
MAPR	Mean Annual Peak Runoff
MS4	Municipal Separate Storm Sewer System
NCDC	National Climatic Data Center
NCE	National Commission on the Environment
NHD	National Hydrology Dataset
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NRDC	Natural Resources Defense Council
NYSDEC	New York Department of Environmental Conservation
OLS	Ordinary Least Squares
PC	Plan Component
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RESET	Ramsey Regression Equation Specification Error Test
SHELDUS	Spatial Hazard Events and Losses Database for the United States
SSURGO	Soil Survey Geographic Database
SSWM	Sustainable Stormwater Management
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load

TPQ	Total Plan Quality
USD	United States Dollar
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGBC	U.S. Green Building Council
USGS	U.S. Geological Survey
VIF	Variance Inflation Factor
WCED	World Commission on Environment and Development
WERF	Water Environment Research Foundation

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1. INTRODUCTION

1.1 Background

Since the Clean Water Act (CWA) of 1972 was first established, federal legislation has been governing water resource planning in the United States by controlling both point- and non-point pollution sources. However, stormwater discharges were not specifically addressed in the early stages until urban stormwater runoff was revealed as a significant source of water quality impairment. Before 1987, only 15 of the 50 states had programs promoting stormwater management and only three states in the mid-Atlantic region (Pennsylvania, New Jersey, and Maryland) had established stormwater-related legislation and ordinances (Kaiser & Burby, 1987). Between the late 1970s and early 1980s, stormwater discharges began to be regulated by the National Pollutant Discharge Elimination System (NPDES) permit program. The management process steadily improved after the second amendments of the CWA in 1987. Through the CWA, stormwater pollutants have begun to be controlled systematically, but strategies regarding stormwater quantity issues have not been addressed thoroughly (NRC, 2008). In particular, only a few land use planning, regulations, and incentive programs are employed at the local level to control the stormwater runoff.

Until the 1980s, stormwater management efforts were primarily accompanied by structural measures, such as combined and separate sewer systems. Generally, combined sewer systems are found in many older urban areas, mostly along the east coast and northeastern region (Kloss & Calarusse, 2006; USEPA, 2004). A combined sewer system consists of a single pipe, collecting both sewage and stormwater runoff in the same pipeline. The system is intended to treat all wastewater and stormwater runoff before it reaches streams, rivers, or other bodies of water. However, the major drawback of this system is that runoff easily exceeds system capacity during heavy rainfall, and overflow discharges straightly into the closest water bodies, causing severe downstream water contamination. Since the system includes stormwater, as well as untreated wastes or toxic pollutants from human and industrial activities, the United States Environmental Protection Agency (USEPA) considers the single sewer system to be a critical water pollution concern (Cahill, 2012). In contrast, separate sewer systems, which have separate pipelines for sewage and stormwater, have been constructed in more recently developed areas (Adams & Papa, 2000; USEPA, 2004). Even though the separate sewer system does not contain wastewater, it carries stormwater runoff without treatment, generating severe pollution problems for nearby water bodies. In sum, conventional stormwater management approaches have been highly focused on the symptoms, rather than the problems (e.g., changed development patterns and increased impervious surfaces). Both of these structural approaches have been criticized for their excessive cost and adverse impacts on downstream ecosystems (Kloss & Calarusse, 2006; Randolph, 2004).

Since the 1990s, on-site stormwater mitigation strategies and non-structural measures, such as best management practices (BMPs), low impact development (LID) techniques, and various land use planning tools have been emphasized in flood mitigation. Because property damage and human casualty is continuously increasing in the United States caused by extreme flooding events, it is urgent that local jurisdictions employ effective methods to control potential flooding and its effects generated by developments (Brody et al., 2010). Local planners can apply proactive strategies using strategic comprehensive plans for proper stormwater management and, through strategic implementation, stormwater related issues can be effectively managed.

In recent years, a great deal of research has been conducted to assess the quality of local comprehensive plans in areas including natural hazards, climate change, sustainability, citizen participation, and ecosystem management. However, comparatively little research has been conducted to evaluate local comprehensive plan quality with regard to stormwater management. Further, there has been no empirical research to address the impacts of local planning capacities and efforts on runoff depth over time.

1.2 Research Objectives

This study established and pursued two objectives. First, to better understand whether local jurisdictions within the Chesapeake Bay watershed thoroughly integrate the principles of sustainable stormwater management into their comprehensive plans, this study systematically evaluated the quality of plans based on the developed plan coding protocol. The study examined which specific factors may contribute to explaining the variation in the plan quality. Second, this study examined whether planning capacities have significant impacts in producing less mean annual runoff and mean annual peak runoff. By employing multivariate regression analyses, this study investigated the degree of association of planning factors and other contextual variables with annual mean and peak runoff.

Consequently, this study answered three overarching research questions: 1) *Have local jurisdictions in the Chesapeake Bay watershed adequately integrated the principles of sustainable stormwater management into their comprehensive plans?* 2) *What are the specific factors that promote the integration of sustainable stormwater management principles and local comprehensive plans?* 3) *Do local planning capacities have significant effects on mean and peak annual runoff?*

1.3 Research Significance

Theoretically, this study defines the concept of sustainable stormwater management through understanding the history and trends of stormwater management, reflecting various previous studies, and linking with the process of landscape and urban planning. Sustainability has been used in various disciplines and employed as one of the primary goals in numerous plan documents and projects. Although stormwater management is one of the most important infrastructure of communities to protect the environment, improve public hygiene, and mitigate flood impacts, only a small number of studies identify the concepts of sustainable stormwater management. Through the content analysis, which transforms qualitative documents into quantitative data, sustainability indicators have been developed, along with a new framework for assessing sustainable stormwater systems. Local plan quality was scored and mapped to identify local governments in the study area that are committed to seeking sustainable stormwater systems through comprehensive plans.

Methodologically, this study quantitatively examined the relationship between local plan quality and surface runoff. The condition of current local comprehensive plans can be one of the most important attributes for understanding jurisdictions' visions and perspectives on pursuing sustainable development. In the end, a statistical model was generated to explain the linkage of various factors of surface runoff and can reveal planning measures that can effectively minimize future runoff.

Educationally, this study has the potential to assist the general public and local, state, and federal government agency staff to understand the role of sustainable stormwater management on improving the overall quality of communities, as well as watersheds and landscapes. In addition, effective suggestions about policy implementation can be made, based on the regression analyses.

In summary, this study provides implications for the planning practice by examining the impacts of planning capacities on the surface runoff reduction. The coding protocol for sustainable stormwater management and results from this study may assist local planners and decision-makers to generate more clear and detailed strategies, policies, and ordinances as well as help set priorities for implementing sustainable stormwater management practices. The regression analysis results allow local decision-makers to identify the extent to which factors are most effective in reducing surface runoff. Hence, this study may prompt them to allocate a higher percentage of their budgets towards effective stormwater management strategies and natural/built environments, or on policy/ordinance development.

1.4 Dissertation Structure

This dissertation has five sections. Section 1 gives a brief background of the research, states research objectives and questions, and highlights the significance of examining this research.

Section 2 reviews overall literature relevant to this research. This section specifically reviews the past plan quality evaluation as well as stormwater management research literature. The subsections present a conceptual definition of stormwater management and of sustainable stormwater management, develop principles of sustainable stormwater management, integrate sustainable stormwater management principles into local comprehensive plans, and review previous plan quality and evaluation literature.

Sections 3 and 4 are independent studies. Both sections have an independent abstract, introduction, literature review, research methods, results, discussion and policy implications, and conclusions. Section 3 focuses on evaluating the quality of local comprehensive plans and determines which specific factors significantly contribute on the plan quality score. Section 4 examines the relationships between four sets of independent variables and mean/peak annual runoff by employing a fully specified model. Specifically, this section investigates the effect of local planning capacities on reducing mean/peak annual runoff.

Section 5 summarizes the key findings of Sections 3 and 4 and suggests policy recommendations to local planners and decision-makers.

2. PLAN QUALITY EVALUATION AND SUSTAINABLE STORMWATER MANAGEMENT: A LITERATURE REVIEW

This section outlines and reviews the major literature relevant to the overall research and is organized by four subsections: build an understanding of stormwater runoff and stormwater management; develop key principles of sustainable stormwater management; integrate sustainable stormwater management principles into local comprehensive plans; and review existing plan quality and plan evaluation research. Since the dissertation is composed of two independent studies (Sections 3 and 4), more details can be found in the introduction to each section.

2.1 Understanding Stormwater Runoff and Stormwater Management

Generally, stormwater runoff refers to "the water associated with a rain or snow storm that can be measured in a downstream river, stream, ditch, gutter, or pipe shortly after the precipitation has reached the ground" (NRC, 2008, p. 12). Because the lag time between measured stormwater runoff and rainfall relies on the size of watershed and the capacity of existing drainage systems, small and urbanized watersheds have a relatively short lag time compared to large watersheds (NRC, 2008). Thus, highly urbanized areas tend to have more issues triggered from surface and stormwater runoff.

Stormwater runoff causes serious non-point source pollution by degrading water qualities and altering the morphology of receiving waters (Paul & Meyer, 2001; Morison, 2009). Unlike point source pollution, such as factories and wastewater treatment plans, non-point source pollution originates from dispersed widespread range of locations, generated mostly by rainfall (TCEQ, 2010). Non-point source pollutants come from various areas, such as construction sites, farms, and driveways during heavy rainfall events (TCEQ, 2010). These pollutants are more difficult to control than point source pollutants due to numerous diffuse discharge points and various pollutant source types and hence, promote contamination to the natural environment and cause property damage to the urban environment (Campbell et al., 2004; TECQ, 2010; USEPA, 1983). The USEPA (1992) states that stormwater runoff is the greatest contributor among the point and non-point sources that pollute urban waterways. Forty percent of impaired water bodies were caused by the polluted stormwater runoff in the US (USEPA, 2007). Aquatic ecosystems and riparian environments can be also impaired by the disturbance of natural hydrology (Booth & Jackson, 1997; Paul & Meyer, 2001; Schueler, 1994). Moreover, excessive runoffs arouse flooding, especially in low elevations or poorly drained areas (Hollis, 1975; Morison, 2009; Shuster et al., 2005).

The various approaches to control and mitigate the volume, path, and quality of runoff stemming from urbanization are so called stormwater management (Kaiser & Burby, 1987). The term “stormwater management” incorporates an extensive range of related subjects, including erosion control, watershed protection, floodplain management, and various drainage facility designs (Pyzoha, 1994). The main objective of stormwater management is to systematically utilize components of drainage systems by minimizing combined sewer overflows and supporting the capacity of existing infrastructure in order to preserve and mimic the natural hydrological cycle as pre-development conditions (Adams & Papa, 2000). However, since drainage problems tend to be perceived as a tangential issue in a municipality, a vast number of local jurisdictions did not allocate sufficient budget for the management of stormwater runoff. In many area, planners tend to be more reactive rather than proactive in coping with stormwater issues (Pyzoha, 1994).

2.2 Concepts and Principles of Sustainable Stormwater Management

2.2.1 Sustainable Development

To "sustain" means to "provide what is needed to exist, maintain, and continue or last" (Merriam-Webster.com, 2013). The term "sustainability" originated in biology and ecology studies to signify that an ecosystem can be sustained when its level of animal population and species is maintained (Beatley, 1998). An important concept connected to sustainability is ecological carrying capacity. A causal sequence of adverse effects may occur if it surpasses capacity (Beatley, 1998). Many studies from academic institutions, government agencies, and international organizations have linked sustainability to various subjects. Numerous projects in environmental planning and management have examined how resources can meet the needs of a present populations and future generations. Beately (1998) mentioned that sustainability can be explicitly applied to planning through the use of renewable/non-renewable resources and via natural services delivered from the environment.

"Sustainable development" became a widespread term after it was defined by the World Commission on Environment and Development's (WCED) 1987 report Our

Common Future (or Brundtland report). The report defined sustainable development as meaning to “meet the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987, p. 8). In 1993, the National Commission on the Environment (NCE) also defined sustainable development as “a strategy for improving the quality of life while preserving the environmental potential for the future, of living off interest rather than consuming natural capital” (NCE, 1993, p. 2).

While there is no explicit definition held in common on sustainable development, previous literature in planning practice conceptualized its definition and it can be summarized by four major attributes (Berke & Conroy, 2000). They are:

1) sustainable development should be reproducible to meet the needs of current and future developments and plans (Campbell, 1996);
2) it should balance economy, environment, and equity dimensions (often referred to as the three E’s; to maintain economic growth, protect natural resources, and reduce inequity (Campbell, 1996; Kaiser et al., 1995; Neuman, 1999);
3) local plans should be linked with global concerns (Mega, 1996);
4) sustainable development ought to be dynamically processed to incorporate the distinctive characteristics of plans, which change and update continuously (Maclaren, 1996; Shepard & Ortolano, 1996).

The above definitions reveal that one of the key concepts of sustainable development is protecting and providing safe, flexible, and sufficient environmental resources. By referring the characteristics of sustainable development, eight major principles of sustainable stormwater management have been developed.

2.2.2 Sustainable Stormwater Management Principles

Recognizing the significance of sustainability, several studies integrated this concept of sustainability in stormwater management system, with much attention given to the four aspects of sustainable development, which are: environmental, economic, social, and institutional (Brown, 2005; Brown et al., 2009; Cettner et al., 2014; Morison, 2009). For instance, a survey from nine water professionals in Sweden revealed that the central framework of sustainable stormwater management is environmental-technical sustainability, a notion mainly concerned with reducing flooding and improving water quality (Cettner et al., 2014). Through a survey and early literature review, Cettner et al. (2014) concluded that linking the existing pipe system with various non-piped strategies, such as stringent political support and green infrastructure measures, which encompass societal aspects (recreation and aesthetic), is recommended to successfully develop systems that include sustainable urban stormwater management. Cheng et al. (2013) argued that the concepts of sustainable stormwater management can be achieved by management of the addition of impervious surfaces caused during rapid urbanization. The authors emphasize the integration of both structural and non-structural measures in regulating land cover changes. Other researchers further highlight the importance of local planning institutions and organizations during the planning processes to promote sustainable stormwater management (Cettner et al., 2013; Brown, 2005; Stahre, 2002;

Wong, 2001). In particular, internal collaboration within city departments in addition to external cooperation with nearby local jurisdictions and various organizations are essential components that should be incorporated when developing a wide variety of environmental policies.

For planners to accomplish sustainable stormwater management, they need increased knowledge transfer and education opportunities about non-structural measures. Organizational perspective changes about sustainable stormwater management have led to the development of source-control approaches (McManus & Brown, 2002). Recently, several countries have been focusing on decentralized solutions that could be applied to urban sanitation management (Barbosa et al., 2012). Such solutions are recognized as key to achieving sustainable stormwater management. In the United States, they are labeled as Best Management Practices (BMPs) and Low Impact Development (LID) technologies; Sustainable Urban Drainage (SUD) in England; Water Sensitive Urban Development (WSUD) in Australia; and Low Impact Urban Design and Development (LIUDD) in New Zealand (Cettner et al., 2014; Stahre, 2002). However, BMPs or LID techniques are likely to focus more on technical details without fully interpreting the dimensions of sustainability, which are known to be economic, environmental, social, and institutional. In addition, installing BMPs in a fragmented manner may not sufficiently integrate land-use planning and overall ecological systems (Parkinson & Mark, 2005). By adopting and developing principles of sustainable stormwater management drawn from the current literature, this study combines a broad spectrum of sustainability concepts and techniques.

Given the definition of sustainable development and the concepts of sustainable stormwater management that were established in previous research and various existing local and state stormwater management guidelines, this study developed eight substantive principles of sustainable stormwater management integrating four dimensions of sustainable development: environmental, economic, social, and institutional. The principles are described as follows:

1. *Control impervious surfaces from urban development*: Controlling impervious surfaces is one of the most crucial components to promote sustainability in terms of stormwater management. Land use and land cover changes are known to be the major reason modifying the hydrologic characteristics of a watershed (Chang & Franczyk, 2008; Gearheart, 2007). In particular, during the urbanization process, the natural hydrological cycle is altered and more frequent and extreme flood events occur due to the increase of manmade land covers, which are mostly impervious surfaces (Cheng et al., 2013). A great number of studies have demonstrated that increased impervious surfaces escalate total volume, peak flow, discharge duration, pollutant loadings, and temperature of runoff (Booth & Jackson, 1997; Paul & Meyer, 2001; Schueler, 1994; USEPA, 2009). Thus, impervious surfaces should be controlled during the massive development to successfully implement the concept of sustainable stormwater management by applying various types of structural and non-structural approaches. Specifically, land-use planning tools, such as clustering development, transfer of development rights, conservation easements, density bonuses, setbacks/buffer zones near the

floodplain areas and environmentally sensitive areas, urban growth boundaries, and various zoning controls, are considered to be productive in preserving natural land covers and minimizing damages from flooding (Brody et al., 2006). Connecting smart growth policies with stormwater management is also recognized to limit urban sprawl and minimize the portion of impervious surfaces (Kloss & Calarusse, 2006). While a variety of non-structural measures can be efficient in controlling the increment of impervious surfaces, structural approaches, such as constructed wetlands, porous pavements, filtration basins, and a range of detention, infiltration, and filtration facilities/practices, should also be constructed concurrently in the right places to effectively and sustainably manage stormwater runoff.

2. *Treat stormwater as an asset*: As far as future generations are concerned, water conservation and recycling is the key principle of sustainability. The main objective of traditional stormwater management approaches, which include underground pipes, curbs, and gutters, has focused on removing stormwater as promptly as possible in order to mitigate any impact from flooding in a particular subdivision (Kaiser & Burby, 1987). However, those approaches led the increase of runoff volume and velocity as well as peak flows, which caused downstream water bodies to be more vulnerable to flooding (Urban Land Institute et al., 1975; Kaiser & Burby, 1987). Today, stormwater can be utilized as a valuable resource. By using the rainwater harvesting systems, rainfall can be reused and the quantity and quality of street runoff can be reduced and improved. Moreover,

groundwater can be recharged if it is clearly filtrated by LID facilities such as green swale, green roof, and bioswale. Retention ponds can be used as the heart of urban parks and enhances landscape aesthetics. Furthermore, stormwater runoff can be reused for irrigation for parks and community gardens (Huber, 2010).

3. *Preserve, integrate, and understand existing natural features and systems by incorporating ecosystem management*: For an effective implementation of sustainable stormwater management, it is important to integrate natural systems, such as a greenway system. When designing the Boston park system during the 1870s, Frederick Law Olmsted managed urban stormwater by using natural systems (Spinner, 2002). In addition, as with McHarg's approach to natural resources, sustainable stormwater management should reconnect people with nature by letting nature do the work (Spinner, 2002). Understanding the natural systems can be the best way to efficiently manage stormwater (Yang & Li, 2011). Overall, rather than relying only on the traditional pipe-system, integrating ecosystem services—such as protecting natural areas—and applying ecological design would further improve the quality of the environment and mitigate impacts from excessive runoff (Cheng et al., 2013). Utilizing native vegetation and open space also provide economic benefits by saving drainage system costs.
4. *Reduce drainage-related costs and increase funding opportunities*: Economic validity should be assured by local governments in adopting sustainable goals,

policies, and regulations. Urban sprawl has wrought huge amounts of infrastructure-related installation expenses (Gaffney, 1964). The USEPA (1988) recognized that the cost of traditional water treatment processes is high enough to give economic pressures and recommended alternative approaches to control water pollution, approaches that are creative and cost effective. Sustainable stormwater management approaches, such as green infrastructure practices and LID techniques, have been proved to be cost-effective compared to traditional pipe-oriented drainage systems (OFUE, 2013; USEPA, 2010). Unfortunately, urban stormwater management-related infrastructure has received less attention and funding from local governments than other governmental infrastructure activities, such as road and land construction, which are classified as mainstream works (Dollery & Marshall, 1997; Pyzoha, 1994). However, as stormwater-related destruction is rapidly growing in urban areas and more chances are given by federal and state funding on LID techniques, local governments are starting to develop a wide variety of stormwater management programs. In summary, local governments should further adopt sustainable stormwater management practices so as to reduce the construction and maintenance costs of stormwater infrastructure, to increase life cycle cost savings, and to receive more funding opportunities on stormwater utilities. Besides, well-designed LID facilities may increase land values, reduce energy consumption and costs, and encourage economic development (USEPA, 2013).

5. *Enhance urban landscape aesthetics and recreational opportunities*: Sustainable stormwater management should incorporate social aspects. Structural approaches of sustainable stormwater management will be mostly constructed above the ground rather than being hidden underground as traditional pipe-drainage systems are. Therefore, they will provide better landscape aesthetics and enhance a community's social composition by reducing crime rates and mental or behavioral illnesses (OFUE, 2013). In addition, well-designed retention ponds within urban parks and green spaces will provide more recreational opportunities with a better built-environment. However, some poor communities may be located in low-elevation or near the high-risk floodplains due to inexpensive housing costs. Since they have higher chances of damages triggered by excessive runoff, installation of BMPs and LIDs should be properly and equitably placed and, to achieve social goals, priority should be given to these areas.
6. *Encourage public participation*: Sustainable stormwater management can be achieved through active participation of various stakeholders within a community during the planning process (Stahre & Geldof, 2003). The participation process is as important as the outcome. Public opinion should be fruitfully reflected during the development procedure in order to enhance residents' responsibility and to create an effective management plan. Public education could motivate the public as well as officials to increase efforts and investments in stormwater management programs (Visitacion et al., 2009). In addition, LID practices can be successfully implemented when diverse stakeholders are involved during the planning

procedure, including residents, developers, and government agencies (Huber, 2010). Implementing training workshops and creating websites or printed material related to stormwater management techniques could considerably encourage public interest and support building knowledge in managing stormwater (Brody et al., 2010).

7. *Require dynamic involvement and cooperation of various departments during the planning process*: Sustainable stormwater management can be implemented through dynamic involvement and cooperation of various city departments (Stahre, 2002; Stahre & Geldof, 2003). To effectively manage urban stormwater with a widespread understanding of economic, environmental, and social dimensions, incorporating various stakeholders through the planning process is inevitable (Wong, 2001). Without internal collaboration, a plan may not integrate multiple issues that derive from diverse environments. Additionally, some researchers found that the role of water professionals is crucial during the planning process to effectively manage stormwater (Cettner et al., 2013). Since the current planning system does not incorporate the commitment of staff members in water departments, it is challenging to design sustainable stormwater management prior to developing a plan. By embracing planning approaches and water-related engineering approaches, more sustainable stormwater perspectives can be applied before new and redevelopment processes (Cettner et al., 2013).
8. *Collaborate with various governments and organizations*: Stormwater cannot be fully controlled by a single community or government. Stormwater runoff is

generated from different sources and ecological systems, which often have a boundary across multiple jurisdictions. Local governments are encouraged to collaborate with nearby governments, organizations, or with higher levels of government (state and federal). To effectively implement sustainable stormwater management in Sydney, Brown (2005) recognized the need to alter the organizational administration. In particular, overlapping accountability and conflicts between local government and state government organizations, as well as insufficient and inadequate funding management for stormwater management are known to be major impediments to achieving sustainable stormwater management (Brown, 2005). Thus, key principles for sustainable stormwater management should be intimately related with various governments and organizations.

2.3 Integrating Sustainable Stormwater Management Principles into the Local Comprehensive Planning

This subsection summarized why the major sustainable stormwater management concepts and principles should be addressed and integrated into local comprehensive planning. First, a local comprehensive plan is a long-range policy document, generally known as a “blueprint” for a city or county’s future development (Kaiser et al., 1995). Most land use and zoning decisions are made based on the visions, goals, and policies that are exemplified within the comprehensive plan. Specifically, since subdivision regulations as well as public work projects should be consistent with the direction of comprehensive plan to be approved, local governments should incorporate a broad view and general concept of sustainable stormwater management in order to effectively implement specific actions.

Second, comprehensive plans contain a wide variety of elements, including land use, population, circulation, housing, environmental resources, economy, hazard mitigation, community facilities and services and so on. If the key concepts of sustainable stormwater management are incorporated into the plan, the implementation effect will be more influential by encompassing the understanding of sustainable stormwater management in various elements rather than being considered solely within a separate stormwater management plan or program.

Third, comprehensive plans are developed based on thorough planning processes and factual bases. Identifying in-depth information, such as flood-vulnerable areas, total impervious areas, and future land use planning, will help establish better policies and strategies with respect to sustainable stormwater management principles.

Fourth, comprehensive plans are developed through combined analyses by experts from various fields and are built by public consensus (Berke & Godschalk, 2009; Norton, 2008). During the planning process, broad and diverse community voices can be heard before the implementation. In this way, plans can contain consistent and comprehensive contents regarding stormwater management in the initial phases.

Fifth, comprehensive plans are updated consistently with extensive review processes. Because they are typically revised every five-to-ten years, communities may continuously update and integrate innovative and newly developed stormwater management techniques (Brody et al., 2004; Fu & Tang, 2013).

Lastly, the policy-making process of the comprehensive plan is proactive, not reactive, which enables communities to be prepared for the risks arising from stormwater-related issues (Brody et al., 2004). In addition, as of 2010, twenty-seven states mandate local governments to adopt and develop local comprehensive plans in the US (Institute for Business and Home Safety, 2010). This shows that the role of comprehensive plan is becoming more influential for local governments and that the probability of implementation of sustainable stormwater management concepts, principles, and related codes is increased.

2.4 Plan Quality and Plan Evaluation

Since 1941, the term "content analysis" began appearing in systematic analyses of various texts (Krippendorf, 2013). Traditionally, the phrase has been used for analyzing newspapers, journals, novels, and other diverse manuscripts to characterize and assess contexts, assumptions, and attitudes (Norton, 2008). Although content analysis was introduced in the early 1900s, several researchers from the mid-1990s began applying the concept to evaluate the context and the quality of plans as well as their implementation (Berke et al., 2006; Laurian et al., 2004, 2010). Berke and French (1994) claimed that this was due to early experts' perspective on planning, which concentrated on the processes and methods of plan making, but not on the quality or components of the plans themselves.

With regard to plan evaluation, the existing literature demonstrated that plan evaluation plays an important role in supporting policy makers' decisions. Indeed, the planning process, as well as its implementation strength, can be indicated by plan quality (Dalton & Burby, 1994; Talen, 1996). Some early plan quality studies conceptualized evaluating plan quality by emphasizing the goals and objectives criteria. For instance, by focusing on the land use and housing categories within a plan, Boyce (1970) and Fishman (1978) stated that goals and objectives—appropriately linked with local circumstance and specifically delineated policies—may yield plans of higher quality. Other researchers have emphasized clear and well-defined policies and maps, as well as consistency between goals/policies and key principles being important attributes of plan quality evaluation (Kent & Jones, 1990). More recently, Berke and French (1994) evaluated plan quality on state-planning mandates by including factual basis, goal, and policy components. Baer (1997) suggested several fundamental criteria for plan assessment from previous studies: adequacy of content; adequacy of scope; approach, data, and methodology; guidance for implementation; plan format; procedural validity; "rational model" considerations; and quality of communication. Baer (1997) stated that plans based on such criteria should be incorporated into future developments.

Kaiser, Godschalk, and Chaplin (1995; Urban Land Use Planning) may be the pioneers that conceptually identified and systematically developed the major attributes of plan quality. Plan components that they classified for plan evaluation form some of the most frequently used frameworks in the current literature. There are three plan components: fact bases, goals, and policies. A strong fact base in a plan allows a community to ascertain the current local conditions and determine what issues exist within a community by providing an inventory of present and future conditions. Clear goals, which include "aspiration, problem abatement, and needs that are premised on shared values," can help a community develop well-defined and desired future conditions (Brody, 2001, p. 41). Certain policies make goals be more readily achieved and provide detailed guidelines for developments to assure plan goals (Berke & French, 1994; Brody, 2001; Brody et al., 2006). In particular, Brody et al. (2006) emphasized that high-quality plans should be formulated on a stringent factual basis, with clear goals, and through specific and direct policies. Starting from the mid-1990s, a sequence of plan quality studies have been quantitatively examined, especially in the area of natural hazards. Based on the measurement processes and conceptual framework of plan quality that Kaiser et al. (1995) defined, various plan quality studies have, in recent years, developed their own evaluation coding protocol and applied it to diverse fields. Specifically, Brody (2003b, 2003c) examined the local plan quality in terms of ecosystem management in Florida and further developed the existing "three plan components" framework by adding two additional plan components. These are "implementation" and "inter-organization coordination and capacities." Implementation refers to the ability whether local governments have enduring provisions to carry out specific actions (Brody, 2008; Stevens, 2013). Inter-organizational coordination and capabilities refer to the degree in which a local government has a capability to cooperate with other adjacent governments and various organizations (Berke et al., 2013; Brody, 2008). The five-components approach enables planners to manage more diverse and substantial matters, such as ecosystem management and watershed protection. Brody (2003c) and Brody et al. (2004) used the five components to examine the degree to which local plans incorporate ecosystem management principles. Tang et al. (2008) employed 37 indicators within five plan components to measure the quality of hazard mitigation and management plans in America's Pacific coastal counties. Tang (2008) also used five components when evaluating coastal zone land use plans in California to ascertain the factors affecting coastal zone land use planning capacities. Fu and Tang (2013) evaluated local comprehensive plans to determine which jurisdictions had the most thorough drought preparedness planning by using the five-components approach. Table 2.1 shows the summary of previous plan quality evaluation studies.

Table 2.1. Previous Plan Quality Evaluation Research

Research area	Previous studies	N
Affordable housing	Hoch, 2007	1
Citizen participation	Brody, 2003a; Burby, 2003	2
Climate change	Baker et al., 2012; Bassett & Shandas, 2010; Brody et al., 2008; Hamin, 2011; Stone et al., 2012; Tang et al., 2010; Wheeler, 2008	7
Coastal management	Davis, 2004; Deyle & Smith, 1998; Norton, 2005; Tang, 2008; Tang et al., 2011	5
Comprehensive plan	Stevens, 2013	1
Ecosystem management	Berke et al., 2013; Brody, 2003b, 2003c; Brody et al., 2004; Brody & Highfield, 2005; Termorshuizen et al., 2007	6
Environmental plan / protection	Berke, 1994; Evans-Cowley & Gough, 2008; Steelman & Hess, 2009; Tang & Brody, 2009	4
Green infrastructure	McDonald et al., 2005; Youngquist, T, 2009	2
Land use pattern	Kent & Jones, 1990	1
Natural hazards	Berke et al., 1996, 1997, 2012; Berke & French, 1994; Brody, 2003a; Burby & Dalton, 1994; Burby & May, 1997; Burby et al., 2000; Burby, 2005; Deyle et al., 2008; Fu & Tang, 2013; Godschalk et al., 1999; Horney et al., 2012; Kang, 2009; Kang et al., 2010; Nelson & French, 2002;	20

Table 2.1. Continued

Research area	Previous studies	N
Natural hazards	Olonilua & Ibitayo, 2011; Olshansky, 2001; Srivastava & Laurian, 2006; Tang et al., 2008	
New urbanism	Evans-Cowley & Gough, 2009	1
Physical activity	Aytur et al., 2011; Evenson et al., 2012	2
Smart growth	Edwards & Haines, 2007; Talen & Knaap, 2003	2
Sustainable development	Berke & Conroy, 2000; Berke, 2002; Conroy & Berke, 2004	3
Urban sprawl	Brody et al., 2006	1

3. MANAGING STORMWATER FOR URBAN SUSTAINABILITY: AN EVALUATION OF LOCAL COMPREHENSIVE PLANS IN THE CHESAPEAKE BAY WATERSHED REGION

3.1 Synopsis

As excessive stormwater runoff continues to be an environmental concern to the nation, several initiatives and regulations have been recently developed at the regional and national level to manage stormwater in a more effective and sustainable manner. Few local jurisdictions, however, have sufficiently adopted policies regarding stormwater management in their local plans until now. To examine whether local comprehensive plans have adequately integrated the concepts of sustainable stormwater management, this study systematically evaluates the quality of 76 comprehensive plans in the Chesapeake Bay watershed using the developed plan coding protocol. The study also empirically identifies factors that significantly influence the quality of plans in the sample. The Chesapeake Bay watershed was chosen for the investigation because the bay has been critically polluted by urban and suburban stormwater runoff resulting from the rapid growth of its nearby jurisdictions. The findings indicate that the majority of local governments have not successfully incorporated the sustainable stormwater management principles in their comprehensive plans. The results from multiple regression analysis show that the plan adopted year, historical flooding/storm surge events, and impervious surfaces influenced on sustainable stormwater management plan quality significantly. The current study concludes with policy implications and recommendations to increase awareness and understanding of sustainable stormwater management concepts and to produce better implementation plans that integrate comprehensive stormwater, ecosystem, and environmental planning.

3.2 Introduction

Urban and suburban stormwater runoff has become one of the major threats across the globe that cause numerous adverse impacts to water bodies. It triggers more frequent and severe flood events, erodes streams, increases water temperature, degrades fish habitats, impairs water quality, and produces many other issues (CBF, 2014; Lehner et al., 1999). In the US, property damage caused by flooding was USD 3 billion in 2008, and approximately USD 750 million (25%) originated from uncontrolled urban and suburban stormwater runoff, which includes flooded basements, sinkholes, and eroded roads (CBF, 2014; Wright, 2008). Stormwater runoff was also responsible for impairing the Chesapeake Bay watershed by transporting a significant amount of phosphorus (32%), nitrogen (16%), and sediment loads (28%) into the bay (USEPA, 2008). In addition to the social and environmental impacts, stormwater runoff has negative economic influences. For instance, the Natural Resources Defense Council (NRDC, 2011) identified that about 18,682 days of ocean, bay, and Great Lake beaches were closed mainly due to the influx of polluted stormwater runoff, and the economic losses were estimated to be approximately USD 37,000 per day.

To control the runoff and minimize the impacts from nonpoint pollution sources, several manmade filtration systems and practices have been employed. However, those structural-based measures highly focused on the symptoms rather than the problems and have been criticized by some researchers due to the expensive building costs and adverse impacts on downstream ecosystems (Booth & Jackson, 1997; Kloss & Calarusse, 2006). Since the 1990s, on-site stormwater mitigation strategies and non-structural measures, such as best management practices (BMPs), low impact development (LID) techniques, and various land use planning tools, became widely employed in reducing flood damage and managing stormwater runoff (Cahill, 2012; Randolph, 2004). Several federal regulations, permits, funds, and programs have also been established to control the quantity and quality of stormwater runoff (NRDC, 2011). However, there has been less attention paid to stormwater management at the local level. Historically, most local governments set a lesser amount of funding with regard to stormwater programs compared to other governmental infrastructure activities, such as road and land construction, which are classified as mainstream works (Dollery & Marshall, 1997; The National Academies, 2009; Visitacion et al., 2009). Given the fact that stormwater runoff damage is continuously increasing in the US and the responsibility and leadership of local governments are becoming more important with repetitive flood events, proactive actions should be taken by local communities. Specifically, enhanced strategic comprehensive planning is required by embracing both structural and non-structural stormwater management approaches to alleviate the increasing flooding vulnerability that is induced by rapid urbanization and climate change (Brody et al., 2010; CBF, 2014).

Creating sustainable communities has become one of the major goals in the planning arena (Brody et al., 2006). Recognizing the significance of sustainability, the fundamental concepts have been integrated into stormwater management system with much emphasis on the four dimensions of sustainable development: environmental, economic, social, and institutional perspectives (Brown, 2005; Brown et al., 2009; Cahill, 2012; Cettner et al., 2014; Morison, 2009; Roy et al., 2008). The primary goals that were suggested in the previous literature tend to place emphasis on the reduction of runoff volume, improvement of water quality, control of impervious surfaces, consideration of social (recreation and aesthetic) aspects, and promotion of internal and external collaboration. A limited amount of research, however, have fully embraced the major concepts of sustainability while defining sustainable stormwater management, and diverse measures (including structural, non-structural, on-site, land use planning) have not considered sufficiently in achieving those concepts. This substantial gap allows this study to specify and elaborate key principles of sustainable stormwater management focusing on local land use planning.

Polluted stormwater runoff is recognized as a local problem, which requires comprehensive local solutions (CBF, 2014). With the establishment of US CWA's NPDES program, stormwater runoff has been mostly regulated at the local level in the US (Roy et al., 2008). Since many factors causing stormwater runoff such as rapid urbanization, urban sprawl, and inadequate drainage system occur at the local level, the role of local land use decisions are becoming more crucial in managing stormwater (Brody et al., 2004; Kaiser & Burby, 1987). A local comprehensive plan is a long-range policy document, generally known as a “blueprint” for a city or county’s future development (Kaiser et al., 1995). A number of studies have used local comprehensive (or land use) plans as a measurement to examine the capability of localities on preparing for various natural hazards, including flooding, drought, and earthquake (Berke et al., 1999; Brody, 2003a; Burby et al., 2000; Fu & Tang, 2013; Godschalk et al., 1999; Tang et al., 2008). In addition, some research examined the degree to which local plan quality has a subsequent relationship with specific phenomenon, including flood damage, earthquake damage, and wetland development pattern (Brody & Highfield, 2005; Burby et al., 1998; Kang, 2009; Nelson & French, 2002). While plan quality has often been examined in understanding local hazard mitigation planning and employed as a key indicator of implementation in a great deal of previous research, only a limited number of studies have integrated the concepts and principles of sustainable stormwater management into local comprehensive plans. Laurian et al. (2004, 2010) evaluated the outcomes of local plans associated with stormwater management issues in New Zealand by reviewing whether land development permits have been developed following the local land use plans. Berke et al. (2013) used five stormwater indicators while evaluating local land use plans in terms of Jordan Lake watershed protection in North Carolina. Stevens et al. (2010) used the number of stormwater BMPs as flood hazard mitigation techniques and examined whether New Urbanism design is more resilient to natural hazards compared to conventional development patterns. However, few, if any, studies addressed the extent to which local comprehensive plans integrated the concepts of sustainable stormwater management.

This study develops an evaluation protocol building on previous plan quality conceptions (Brody, 2003a) to understand the integration of sustainable stormwater management principles within local comprehensive plans. Seventy-six local comprehensive plans within the Chesapeake Bay watershed were evaluated. Analyses identify the extent to which local jurisdictions have developed a strong plan towards sustainable stormwater management. Eight substantive principles of sustainable stormwater management have been developed based on the literature review and they are described in Section 2.2. In addition to scoring the local plans, this study seeks to empirically examine the key factors that contribute on the plan quality score. The findings provide insights for local governments to which planning policies need to be adopted to manage stormwater in a sustainable manner and explain which factors significantly influence on the quality of local plans. Thus, the study seeks to answer the following three research questions:

1. Have local governments appropriately integrated sustainable stormwater management principles into their local comprehensive plans?
2. Which plan components and indicators scored the highest and were used frequently in achieving sustainable stormwater management?
3. What were the effects of planning capacity and other major factors on local sustainable stormwater management plan quality?

3.2.1 Conceptualizing Local Sustainable Stormwater Management Plan Quality

Most land use and zoning decisions are made based on the visions, goals, and policies that are exemplified within a comprehensive plan. In addition, subdivisions regulations as well as public work projects should follow the direction of comprehensive plan to be approved. Because stormwater-related ordinances, codes, and regulations directly impact on future land developments, they should be implemented based on the overall goal of a comprehensive plan. Although plan evaluation may not assure that specific policies will be implemented in the real world, sustainable stormwater management goals can be better promoted when its plan quality receive higher score (Berke & Godschalk, 2009).

To understand whether the key principles of sustainable stormwater management have been thoroughly integrated into local comprehensive plans and policies, this study built up theoretical supports for measuring plan characteristics and used the content analysis method that was employed by a great deal of previous plan quality studies (Berke & Conroy, 2000; Brody et al., 2004; Conroy & Berke, 2004; Lyles & Stevens, 2014; Stevens, 2013; Tang et al., 2010). A conceptual definition of local sustainable stormwater management plan quality was established by adopting the conceptions (five plan components) that Brody (2003c) applied in evaluating the local ecosystem management plan quality. Since stormwater runoff is likely to be controlled effectively at the watershed level, the protocol that was developed for trans-boundary natural systems will be an appropriate approach for this study. To be specific, plan quality was measured by applying three key components that Kaiser et al. (1995) identified (factual basis; goals and objectives; policies, strategies and tools) as well as additional two components (inter-organizational coordination and capabilities; and implementation) that Brody (2003c) used for the plan quality evaluation.

Appropriate indicators (or items) for each component are developed based on several earlier studies on sustainable development (Berke & Conroy, 2000), ecosystem management (Brody, 2003c; Brody, 2008), flood mitigation (Brody, 2003a; Kang et al., 2010), climate change (Tang et al., 2010), drought resilient planning (Fu & Tang, 2013), and general comprehensive plan evaluation (Stevens, 2013), as well as various guidelines on stormwater management. Guidelines include: Low-Impact Development Design Strategies: An Integrated Design Approach (Prince George's County, 1999), Urban Stormwater Quality Planning Guidelines (DEHP, 2010), Georgia Stormwater Policy Guidebook (Atlanta Regional Commission, 2001), Municipal Stormwater Management (Debo & Reese, 2003), A Handbook for Water and Wastewater Utilities (USEPA, 2012), Policy Guide on Planning for Sustainability, Wetlands, Water Resources Management, and Smart Growth (APA, 2000; 2002a; 2002b; 2012), and the U.S. Green Building Council's Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND; USGBC, 2013) rating system.

3.2.1.1 Factual Basis

The factual basis of a stormwater-oriented plan identifies a community's current conditions and future needs on existing natural and manmade resources by assessing the existing status and projecting the issues that will be required for managing stormwater

(Brody, 2008; Stevens, 2013; Tang et al., 2011). Strong factual basis component should identify fundamental information that will be necessary for achieving the concepts of sustainable stormwater management, and thus be a vital basis for establishing specific goals, objectives, and policies (Fu & Tang, 2013). Generally, it is composed of both written and visual information (Brody et al., 2006; Brody, 2008; Berke & Godschalk, 2009; Stevens, 2013). In order to have a stringent factual basis with regard to sustainable stormwater management, this study classified the factual basis into two categories: resource inventory and human impacts. First, the resource inventory category was chosen because the quantity and quality of stormwater runoff can be influenced significantly by the existing and future conditions of natural environments. Indicators within the resource inventory include: *description of vegetation and forests*; *classification/description of soils*; *description of water resources*; and *inventory of local climate*. Second, human impacts are selected as another category since the leading causes of excessive stormwater runoff are from urbanization and population growth. Stormwater management problems started to appear along with the growth of populations in comparatively small areas (Niemczynowicz, 1999). Hydrological cycle has changed due to an increase in developments, especially by the enlarged impervious surfaces, and thus these changes stimulated the decrease of the natural ability of infiltration, reduced the amount of groundwater recharge, increased peak flows and total volume of runoff, and accelerated soil and sediment erosion in and around urban and suburban areas (Niemczynowicz, 1999). Given the facts that human impacts are worsening the stormwater runoff, identification of potential human development threats is necessary. Table 3.1 shows the description of nine indicators including the sources that have been adopted and amended.

Table 3.1. Description of Indicators in the "Factual Basis" Component

Category	Indicators	Sources
Resources	Classification/description of vegetation and forests	Brody, 2003c; Stevens, 2013
Resources	Classification/description of soils	Brody, 2003c; Stevens, 2013
Resources	Inventory of local climate	Brody, 2003c; Fu & Tang, 2013
Resources	Map or inventory of watersheds, wetlands and water resources	Brody, 2003c; Fu & Tang, 2013
Human impacts	Current population and population growth projection	Brody, 2003c; Fu & Tang, 2013; Stevens, 2013
Human impacts	Impervious surface area density and/or road density	Brody, 2003c; Fu & Tang, 2013
Human impacts	Map or inventory of current and/or future land use	Stevens, 2013
Human impacts	Map or inventory of main water pollution types and sources	Brody, 2003c; Fu & Tang, 2013; Stevens, 2013
Human impacts	Present and/or future needs of stormwater infrastructure and services	Stevens, 2013

3.2.1.2 Goals and Objectives

The goals and objectives of a plan should embrace specific descriptions of a community's future visions since they play an important role in guiding local governments to implement and adopt efficient land-use policies (Brody, 2008; Fu & Tang, 2013; Stevens, 2013; Tang et al., 2010). Goals need to be clearly described and be part of a consistent and long-term scheme; objectives should be specified and measurable in order to implement successful stormwater management strategies (Brody, 2008). Without clear goals and objectives, plans and policies cannot be effectively formulated or evaluated (Brody, 2008; Stevens, 2013). To assess the visions of a plan as to whether they are approaching sustainable stormwater management, eleven broad goals and objectives are employed in this study. Two indicators evaluate the general features of the goals and objectives (*goals are clearly specified; presence of measurable objectives*). The other seven indicators are used to assess the sustainability of plans on stormwater management. Table 3.2 summarizes the description of eleven indicators in the "goals and objectives" plan component.

Table 3.2. Description of Indicators in the "Goals and Objectives" Component

Indicators	Sources
Goals are clearly specified	Brody, 2003c
Presence of measurable objectives	Brody, 2003c
Control/reduce stormwater runoff and/or flood	ARC, 2001; APA, 2002a; Debo & Reese, 2003; DEHP, 2010; USEPA, 2012
Improve water quality	ARC, 2001; APA, 2002a; Debo & Reese, 2003; DEHP, 2010; USEPA, 2012
Minimize impervious surfaces from development	Debo & Reese, 2003; DEHP, 2010; USEPA, 2012
Promote low impact development	APA, 2000; DEHP, 2010; Fu & Tang, 2013
Promote smart growth	APA, 2012; DEHP, 2010
Protect natural processes/functions	Brody, 2003c
Protect integrity of ecosystem	Brody, 2003c
Establish adequate funding for stormwater management	APA, 2002a; USEPA, 2012
Maintenance of stormwater management facilities	ARC, 2001; Debo & Reese, 2003
Encourage open spaces/recreation actions	ARC, 2001; APA, 2000, 2012
Encourage public participation	APA, 2000

3.2.1.3 Inter-organizational Coordination and Capabilities

Stormwater regulations and policies for a small subdivision development can be managed adequately within the boundary of jurisdiction. However, stormwater runoff is generated from different sources and ecological systems. In particular, the amount of runoff can be influenced considerably by the size and shape of watershed or topography, which often has a boundary across multiple jurisdictions. In addition, developments near the upstream areas may impact downstream runoff volume and water quality. If upstream and downstream areas are located within a different jurisdictional boundary, the role of inter-organizational coordination and capabilities will become more important and imperative. Inter-organizational coordination and capabilities refer to the degree to which a local government has the capability to cooperate with other adjacent jurisdictions or state, federal, and higher levels of governments, and various organizations on solving trans-boundary issues (Berke et al., 2013; Brody, 2008). Thus, indicators such as coordination and information sharing with other jurisdictions, organizations, and stakeholders should be identified and specified (Brody, 2008). Additionally, internal collaboration within a jurisdiction plays a critical role in integrating multiple issues that are derived from diverse environments and to developing a comprehensive stormwater management plan. Hence, dynamic involvement and cooperation of various city departments are required to incorporate broad understandings on how to manage stormwater in a more sustainable manner (Stahre, 2002; Stahre & Geldof, 2003). Table 3.3 shows the description of seven indicators for this plan component.

Table 3.3. Description of Indicators in the "Inter-organizational Coordination and Capabilities" Component

Boundary	Indicators	Sources
Beyond	Other jurisdictions/organizations/stakeholders identified	Brody, 2003c
Beyond	Coordination with other jurisdictions/organizations/stakeholders identified	Brody, 2003c
Beyond	Coordination with adjacent jurisdictions	Brody, 2003c
Beyond	Coordination with higher levels of governments (state/federal)	Brody, 2003c
Beyond	Coordination with private sectors	Brody, 2003c
Beyond	Integration with other plans/policies in the region	Brody, 2003c
Within	Coordination within jurisdiction specified	Brody, 2003c
Within	Commitment of financial resources	Brody, 2003c

3.2.1.4 Policies, Tools, and Strategies

Within the comprehensive plan, the most crucial plan component is "policies, tools, and strategies," which is often referred to as the heart of a plan (Berke & Godschalk, 2009; Brody, 2008). These are the measures to actualize the goals and objectives of a community (Brody, 2008; Fu & Tang, 2013; Tang et al., 2011). The indicators in this plan component identify various tools to incorporate the major principles and concepts of sustainable stormwater management based on the existing land use planning and hydrological literature. Specifically, the tools are classified into structural and non-structural approaches.

Structural approaches, if designed properly, are effective tools for minimizing and controlling stormwater runoff. In the past, conventional pipe-drainage systems are the approaches that local governments mainly used to control the stormwater runoff volume. They are effective at rapidly removing excessive runoff and comparatively easy to install within high density urban areas with free of typical land issues. However, their construction and maintenance costs are quite high, and their role is limited, when excessive storm events occur, to controlling stormwater quantity with too little treatment. Thus, natural stormwater mitigation techniques such as retention/detention ponds and constructed wetlands were introduced in the 1980s in the US, and they effectively controlled both water quality and quantity by slowing down the peak discharge rate and storing polluted stormwater for a sufficient time. Even though they occupy large amounts of space and exacerbate flooding, if appropriately located, they function well, harmonizing with natural ecosystems (Perez-Pedini et al., 2005). The practices applied most recently to control stormwater are known as BMPs and LID techniques, which comprise various structural techniques. In some local government plans, these practices are often referred to as green infrastructure. The concept of LID practices is based on on-site source control, which minimizes the excessive runoff and pollution of stormwater at or near its source (Sharpin, 1998). Both structural BMPs and LID techniques have been proved to be effective at controlling runoff volume, minimizing pollutant loads, and enhancing groundwater recharge (Coffman et al., 1999; Zomorodi, 2004). In this study, the protocol includes *innovative stormwater management practices (BMPs/LID techniques/green Infrastructure), certified green building (LEED),* and *constructed wetlands* as indicators for representing structural tools.

Non-structural measures are grouped into five-specific tools: general policies, regulatory tools, incentive tools, land acquisition tools, and awareness tools. General policies imply strategies that incorporate overall concepts of sustainable stormwater management. By having *consistency with other related ordinances and regulations* such as NPDES permits, state/municipal stormwater management programs and plans, and watershed implementation plans, policies can be more effectively implemented.

Regulatory tools have been used as primary non-structural measures in general and thus often employed as key indicators for various plan evaluation studies (Brody, 2003c; Brody et al., 2004; Fu & Tang, 2013; Kang, 2009). Because funding for purchasing environmentally sensitive lands will always be insufficient for local governments, regulations and incentives play crucial roles for an effective implementation (Benedict & McMahon, 2006). In this study, thirteen specific indicators are employed to evaluate whether the concepts of sustainable stormwater management are well-implemented within the local comprehensive plan. By *requiring building codes to have water-efficient facilities*, less stormwater can be generated from impermeable spaces (APA, 2002a; Fu & Tang, 2013). For example, green buildings that involve green roofs, green walls, and rainwater harvesting systems produce less stormwater runoff. To achieve environmental objectives without disturbance from urbanization impacts, land use policies and ordinances such as de*velopment away from floodplains* and *land use restriction near sensitive water bodies* are highly encouraged (Brody et al., 2004). The Clean Water Act also highlights land use restrictions close to sensitive water bodies (Fu & Tang, 2013). *Conservation of local vegetation and forests* allow for protecting the existing natural hydrological cycle, mitigating the flood risk from reduced impervious surfaces, and maintaining the ecosystems (Brody, 2008; Fu & Tang, 2013). Requiring *setbacks and buffer zones* near water bodies and floodplains help reduce damage from excessive runoff. Establishing a buffer width between 100 feet and 300 feet are recommended to protect a wildlife habitat corridor and the quality of water (USEPA, 2005). By following smart growth policies, such as planning *innovative or conservative (low impact development) design for new- and re-developments*, significant amount of impervious surfaces can be reduced (APA, 2012). The *usage of pesticides, herbicides, and synthetic fertilizers* should be properly regulated to reduce the pollution of stormwater runoff. This is because they are easily carried away from excessive storm events and impair downstream ecosystems (APA, 2000, 2002b). *Urban service/growth boundaries* may prevent sprawl and allow local jurisdictions to save expenditures on extending gray infrastructure services and protect water bodies in rural areas (USEPA, 2005). Urban growth boundaries are often used as a blueprint for local land use decisions. Several states in the U.S. such as Oregon, Washington, and Tennessee require municipalities to create urban growth boundaries (Benedict & McMahon, 2006). *Water-efficient landscaping* should be accompanied with a site plan review in order to effectively manage stormwater for new- and re-development sites (Kang, 2009). While land use planning tools are known to be effective in controlling stormwater runoff, there are other approaches to directly regulate the runoff. Indicators that are drawn in this study include: *indicating Total Maximum Daily Load (TMDL), minimizing existing pipelines, monitoring the quality and quantity of stormwater routinely,* and *controlling erosion and sediment* (APA, 2002a; Benedict & McMahon, 2006; Fu & Tang, 2013; USGBC, 2013).

Rather than passing regulatory measures, local governments might find more success by offering incentives if they desire to promote developers' and property owners' adoption of sustainable stormwater management practices (Benedict & McMahon, 2006). Incentive-based tools include several land use planning measures, such as *clustering development*, *density bonuses*, and *purchase/transfer of development rights*. Open spaces and environmentally sensitive areas can be protected from massive developments through these three land-use planning tools. This means that in such manner impervious surfaces can be significantly reduced, thus minimizing the impact from stormwater runoff. Other incentives include: *stormwater fee discounts* and *stormwater impact fees*. Stormwater fee discounts encourage property owners to manage their stormwater runoff by using BMPs and LID techniques and hence receive fee discounts or credits. Stormwater impact fees, which require property owners to pay for the runoff impacts aroused from their lot, help defray the fiscal burden of managing stormwater infrastructure.

Land acquisition programs refer to the capacity of local governments to fund the purchase of crucial lands for protecting water resources (Brody, 2008). By purchasing flood-prone areas, future developments can be avoided and critical habitats as well as water bodies can be protected. Indicators included in this plan component are such strategies as: *fee simple purchase*, *conservation easements*, and *open space preservation*.

Awareness tools assist in enhancing residents and local department officials' perspectives and awareness on stormwater management. Increasing awareness is one of the most essential processes to adopting a sustainable stormwater management plan

(WERF, 2010). *Education and outreach programs* expedite diverse residents to participate in the decision-making process and adequate public support results in a higher quality of plans that can be implemented in the real world (Brody, 2008; Kaplowitz & Lupi, 2012). Facilitating such programs are the provision of a series of workshops, forums, campaigns, and public meetings as well as the utilization of mass media. Setting educational signs where LID practices are performed will also inform the public by providing actual visual examples (WERF, 2010). Local government staffs' insufficient knowledge on stormwater may obstruct the production of an effective stormwater management plan. Thus, *training and technical efforts* such as lectures from water professionals and related conference participation will enhance their ability as well as awareness on stormwater management. *Providing up-to-date floodplain maps or maps of recurrently flooding areas* due to excessive urban stormwater runoff may support residents and officials in preparation for floods and be aware of where future developments should be regulated. Table 3.4 summarizes the description of the 29 indicators for the "policies, tools and strategies" plan component.

Table 3.4. Description of Indicators in the "Policies, Tools, and Strategies" Component

Category	Policies	Indicators	Sources
Structural	**Structural tools**	Innovative stormwater management practices (BMPs / LID techniques / Green Infrastructure)	APA, 2002a; ARC, 2001; Debo & Reese, 2003; DEHP, 2010; Tang, 2010
		Certified green building (LEED)	Tang, 2010; USGBC, 2013
		Constructed wetlands	APA, 2002b
Non-structural	**General policies**	Consistency with other ordinances and regulations	Kang, 2009
	Regulatory tools	Building codes to require water-efficient facilities	Fu & Tang, 2013; USGBC, 2013

Table 3.4. Continued

Category	Policies	Indicators	Sources
Non-structural	Regulatory tools	Development away from floodplains	APA, 2000
		Land use restriction near sensitive water bodies	Fu & Tang, 2013
		Restrictions on local vegetation and forest removal	Brody, 2003c, Fu &Tang, 2013
		Setbacks and buffer zones	Brody, 2003c
		Conservative/innovative (low impact development) design for new-/re-developments	APA, 2012; USGBC, 2013
		Pesticides, herbicides, and synthetic fertilizers (pest control) regulations	APA, 2000, 2002b
		Urban service/growth boundaries	Fu & Tang, 2013; Tang, 2010
		Water-efficient landscaping	USGBC, 2013
		Total Maximum Daily Load (TMDL)	APA, 2002a
		Water quantity and quality monitoring	Fu & Tang, 2013
		Minimum pipe size	Debo & Reese, 2003
		Erosion and sediment control	APA, 2002a; Benedict & McMahon, 2006
	Incentive tools	Clustering development	Benedict & McMahon, 2006; Brody et al., 2006; Fu & Tang, 2013; Kang, 2009
		Density bonuses	Brody et al., 2006; Fu & Tang, 2013
		Transfer of development rights	Benedict & McMahon, 2006; Berke & Conroy, 2000; Brody, 2003c; Brody et al., 2006; Fu & Tang, 2013; Kang, 2009
		Stormwater fee discounts	ARC, 2001; Debo & Reese, 2003; DEHP, 2010
		Stormwater impact fees	ARC, 2001; Fu & Tang, 2013; Randolph, 2004
	Land acquisition tools	Fee simple purchase (land and property acquisition)	Benedict & McMahon, 2006; Brody, 2003c; 2008; Kang, 2009
		Conservation easements	Benedict & McMahon, 2006; Brody, 2003c; Brody et al., 2006
		Open space preservation	Brody & Highfield, 2013
		Other land acquisition techniques	Brody, 2003c
	Awareness tools	Education/outreach program	Brody, 2003c; 2008; Kang, 2009; Kaplowitz & Lupi, 2012; WERF, 2010
		Training/technical assistance	Kang, 2009
		Maps of areas subject to flood hazards or stormwater runoff	Kang, 2009

3.2.1.5 Implementation

The implementation component in a plan refers to the ability of local governments to incorporate enduring provisions that help carry out policies and specific actions (Brody, 2008; Stevens, 2013). The implementation component should be stated unambiguously and involve particular attributes to effectively translate and implement policies into actions: *provide clear time schedule*; *designate responsibilities for agencies*; and *identify clear funding sources* (Berke & Godschalk, 2009; Berke et al., 2013; Stevens, 2013). Table 3.5 shows the description of six indicators for the implementation plan component.

Table 3.5. Description of Indicators in the "Implementation" Component

Indicators	Sources
Clear timeline for implementation	Brody, 2003c; Fu & Tang, 2013; Stevens, 2013
Designation of responsibilities for actions	Brody, 2003c; Fu & Tang, 2013; Stevens, 2013
Identification of financial and technical support	Brody, 2003c; Fu & Tang, 2013; Stevens, 2013
Regular plan updates and assessments	Brody, 2003c; Fu & Tang, 2013
Monitoring of stormwater runoff impacts	-
Highlighting stormwater sustainability	-

A total of 62 indicators were measured in this study to evaluate how well local comprehensive plans incorporate the key principles and concepts of sustainable stormwater management.

3.2.2 Factors Influencing Plan Quality

Although no research up to date empirically examined the factors contributing to integrating sustainable stormwater management principles, the variation of comprehensive plan quality associated with diverse issues, such as ecosystem management and environmental planning, has been explained considerably in previous literature (Brody et al., 2006). An explanatory model was developed and tested in this study based on past research to identify which factors affect local jurisdictions to integrate sustainable stormwater management principles in their comprehensive plans. Specifically, nine independent variables were categorized into three sets of group to test the initial hypotheses: planning capacity, socio-economic characteristic, and stormwater risk.

While local comprehensive planning is affected by various stakeholders and complex conditions of a jurisdiction, plan effectiveness can be improved and better performed by a well-organized pragmatic planning process (Forester, 1984; Lawrence, 2000; Tang & Brody, 2009). Considering this relationship, three planning capacities were measured in this study that may impact the overall strength of a plan: the year that plan was updated, number of planners, and the existence of private consultants involved while adopting a plan. Generally, local jurisdictions update their comprehensive plans in five to six years to monitor existing conditions and reflect changes. More recent plans tend to incorporate up-to-date techniques and information to achieve a plan's initial visions and goals. Given this fact, some studies examined the association of plan updates and local environmental plan quality (Tang & Brody, 2009). This study hypothesizes that plans adopted or amended in more recent times are likely to embrace in-depth policies and strategies and thus, they may have higher plan quality than the outdated plans. A large number of studies have shown that the commitment of planners, planning staff, and elected officials are highly associated with local plan quality (Brody et al., 2006; Burby & May, 1997; Dalton & Burby, 1994; Godschalk et al., 1989; Kang, 2009; Tang & Brody, 2009). More planners during the planning adoption process indicates that there will be more planning inputs, including financial resources and technical expertise, devoted while producing a plan. Thus, more number of planners will increase the likelihood that a plan may integrate sustainable stormwater management principles and policies. In addition, local jurisdictions that have involved private consultants while developing a plan may produce a higher quality stormwater management plan. Hiring private consultants will bring more technical and human resources with which to improve the plan quality.

Hypothesis 1: *Jurisdictions with more recently amended comprehensive plans will result in higher stormwater management plan quality.*

Hypothesis 2: *Jurisdictions with more numbers of planners will have higher plan quality integrating sustainable stormwater management principles.*

Hypothesis 3: *Jurisdictions that hired private consultants will have higher stormwater management plan quality.*

Past studies have also examined the relationship between socio-economic variables and plan quality scores. Population density was used as an important variable for measuring the effectiveness of plan quality (Berke et al., 1996; Brody, 2003a; Brody et al., 2006; Tang & Brody, 2009; Tang et al., 2010). The relationship between population density and plan quality can be mixed (Brody et al., 2006). Jurisdictions with larger populations are more likely, due to more resources and financial support, to have better local comprehensive plans or land-use planning than low-populated jurisdictions (Brody, 2003a). Thus, they will have a higher plan quality on stormwater management, which may help reduce generating urban runoff. At the same time, jurisdictions with high population density also have a greater chance to produce urban stormwater runoff because of more developed land cover and environmental conflicts and pressures (Tang & Brody, 2009). However, compact development patterns and low impact development techniques can be more readily implemented in a jurisdiction with high population. Therefore, this study assumes that high-populated jurisdictions will have a higher stormwater management plan quality. In addition, wealthy and highly educated people are, on average, more environmentally friendly and strongly engaged with environmental problems (Scott & Willets, 1994). Wealthier jurisdictions may also have higher awareness and financial capacity for conserving environmental features and developing higher quality plans, which may help reduce urban runoff (Brody et al., 2004). Brody et al. (2004) identified that wealthier jurisdictions have higher plan quality associated with ecological systems. Moreover, jurisdictions with higher incomes and education levels tend to perform better regarding stormwater management programs compared to poor jurisdictions (Barbosa et al., 2012). Considering the relationship between the two variables that were examined in the previous studies, this study assumes that the jurisdictions with higher median household income and containing more percentages of residents with a high school degree will have a higher quality sustainable stormwater management plan.

Hypothesis 4: *High-populated jurisdictions will tend to produce higher stormwater management plan quality.*

Hypothesis 5: *Wealthier jurisdictions are more likely to have high stormwater management plan quality.*

Hypothesis 6: *Jurisdictions incorporating more educated people will tend to produce high quality stormwater management plans.*

Finally, stormwater risk variables include property damage caused by flooding and severe storm events, the number of storm surge events, and the proportion of impervious land cover. Storm surge events are explicitly related to overland flow and they may produce sudden and catastrophic damages (Brody et al., 2011). Poorly designed drainage systems or highly urbanized areas are apt to be damaged significantly by surge events, which cause excessive urban stormwater runoff. After experiencing historical flooding/severe storm surge damages, a community tends to improve their stormwater management systems to be better prepared from the associated risks. Thus, the jurisdictions that had more flooding/storm surge damage and experienced greater numbers of storm surge events may have higher stormwater management plan quality. Moreover, the amount of impervious surfaces often represents how much an area has been developed or urbanized. An increased percentage of impervious surfaces caused by urbanization affects negative hydrologic impacts, such as excessive runoff, lack of infiltration, and insufficient aquifer recharge (Booth & Jackson, 1997; Brabec, 2009; Paul & Meyer, 2001; Schueler, 1994). However, more urbanized areas are likely to reflect up-to-date stormwater management techniques with sufficient financial resources compared to rural areas. In addition, high-intensity development patterns are often preferred in urban cores. Thus, although urbanized areas have higher threats to be damaged by stormwater runoff, those jurisdictions may establish better goals, objectives, and action strategies to prepare for the future events. Based on these relationships, the hypothesis is made that the jurisdictions with more impervious surfaces are likely to have higher plan quality scores.

Hypothesis 7: *Jurisdictions that had more flooding/storm surge damage will tend to produce higher stormwater management plans.*

Hypothesis 8: *Jurisdictions that have experienced more numbers of storm surge events will tend to have higher stormwater management plan quality.*

Hypothesis 9: *Jurisdictions with more impervious surfaces will tend to generate higher stormwater management plans.*

3.3 Research Methods

3.3.1 Study Area and Sample Selection

The Chesapeake Bay, which is the largest estuary in North America, is a critical area for natural resources, but has been badly polluted due to adverse effects of urbanization. The watershed covers about 166,000 km^2 and it is a habitat of 3,600 species of plants and animals (NYSDEC, 2014). The Bay's watershed encompasses portion of six states in Mid-Atlantic region and the District of Columbia, including Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia (Rice & Hirsch, 2012). In the early 1980s, Section 117 of the Clean Water Act established the Chesapeake Bay Program to protect and restore the ecosystem of the bay. This program aimed to reduce nutrients and sediment flowing into water bodies, protect living resources and ecological vital habitats, and control development within the watershed (Chesapeake Bay Program, 2000). However, the recent study from the USEPA (2008) and the Chesapeake Bay Foundation (2012) revealed that significant amounts of pollutants (nitrogen, phosphorus, and sediment), which are the major contributors on impairing the water bodies, are originating from urban and suburban stormwater runoff, and its proportion is continuously increasing. Therefore, understanding the coping ability of local governments in controlling stormwater runoff may help managing the quantity and quality of runoff more effectively.

The population for this study is the jurisdictions (at county level) within the Chesapeake Bay watershed that have adopted a local comprehensive plan. A total of 203 counties and independent cities lie within or adjoining the watershed. The targeted study area was selected through three steps. First, this study chose local jurisdictions that intersect with the Chesapeake Bay watershed boundary by more than 50 percent to exclude jurisdictions that may not directly influence the watershed ecosystem. Second, counties that have population less than 10,000 were excluded to prevent skew toward small jurisdictions, whereas those often have lack of the resources to initiate a sufficient planning effort (Berke & Conroy, 2000). Third, jurisdictions that have adopted their comprehensive plans between 2000 and 2010 are selected for the final sample. After going through the selection process, 76 counties' comprehensive plans that were available electronically or through individual contacts were collected (see Figure 3.1).

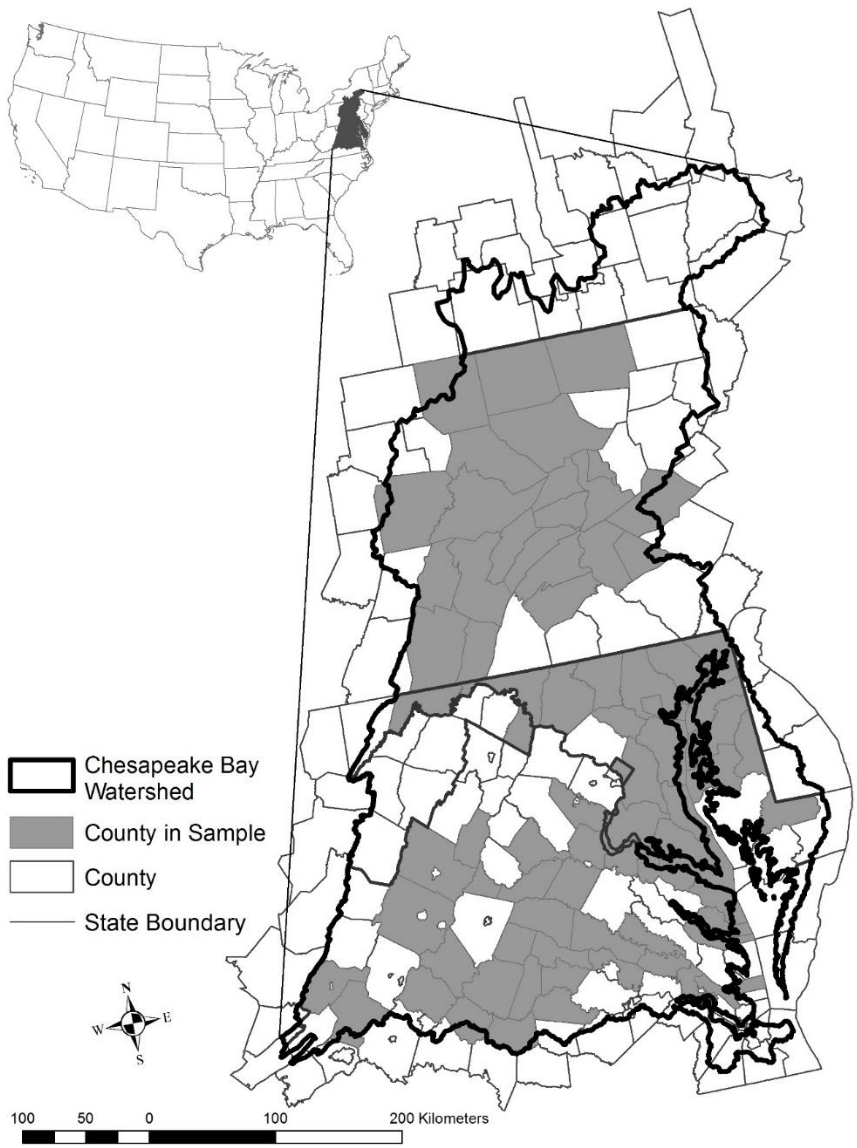

Figure 3.1. Selected Local Jurisdictions in the Chesapeake Bay Watershed

3.3.2 Concept Measurement

3.3.2.1 Dependent Variable: Plan Quality Measurement

Plan quality scores were measured by mainly employing the approach that was commonly used in previous plan quality research (Berke et al., 1996; Brody, 2003c; 2008; Tang et al., 2010). A total of 62 sustainable stormwater management indicators were assessed within five plan components.

Specifically, total plan quality scores for each jurisdiction were calculated based on four steps. First, all indicator scores within a plan component were summed. Each indicator was coded on a 0-2 ordinal scale except the indicators within the *goals and objectives* component, which were measured on a 0-1 ordinal scale. If an indicator was not mentioned or identified within a plan, it was scored 0. When an indicator was identified but not in detail, an indicator was scored 1. If an indicator was completely illustrated and identified within a plan, it scored 2. However, the *factual basis* component and the *policies, tools, and strategies* component had slightly different scoring systems. For the *factual basis* component, indicators were comprised by a map, text, or both. Thus, scores for indicators in this case first added the score of the illustrated approaches and divided by the total number of approaches. For instance, if an indicator scored 1 for a map and 1 for a text, it received a total score of 1 ((1+1)/2). For the *policies, tools, and strategies* component an indicator scored 0 if it was not mentioned within a plan. If an indicator was described by using the moderate words "consider," "encourage," "prefer," "may," "should," and "suggest" within a plan, it received a score of 1. In addition, even though a policy was mentioned within a plan but was not described in terms of "what," "when," "where," and "how," it scored 1. Finally, if an indicator used strong compulsory words, such as "must," "require," "shall," and "will," with a clear description, it scored 2 (Brody, 2008). Second, the total indicator scores within a component were divided by the total available scores that a component can have in order to standardize each plan component. Third, each component score was multiplied by ten to make a scale from 0 to 10. Finally, all five components scores were summed up, which brought the total plan quality score scales from 0 to 50 (Brody, 2008). The plan quality measurement processes are calculated by the following equations (Brody, 2003c; 2008):

$$\boldsymbol{PC_j = \frac{10}{2m_j} \sum_{i=1}^{m_j} I_i} \textbf{.....(1)}$$

where PC_j refers to the quality of the j^{th} plan component; m_j refers to the total number of indicators within the j^{th} plan component (scale: 0-10); I_i refers to the i^{th} indicator's scores (scale: 0-2)

$$\boldsymbol{TPQ = \sum_{j=1}^{5} PC_j} \textbf{.....(2)}$$

where TPQ refers to the entire plan quality scores (scale: 0-50)

In addition, this study examined the performance of indicators to identify the breadth and depth (quality) of each indicator within plans (Brody, 2008; Godschalk et al., 1999; Tang et al., 2010). While the breadth score shows how many plans in the study area address and integrate specific indicators, the depth score demonstrates the degree of detail of a certain policy (Brody, 2008). Specifically, the breadth score was calculated in two stages. The number of plans that stated a specific indicator were first summed and then divided by the total number of plans (scale: 0-1). The depth score was calculated by adding all plans' scores that mentioned a specific indicator divided by the number of plans that mentioned the issue (scale: 0-1). After these steps, both breadth and depth scores were summed to compute the total indicator score (scale: 0-2; except the *goals and objectives* component indicators (scale: 0-1)), which represent the degree to which local comprehensive plans in the study area integrate, on average, the concept of sustainable stormwater management.

3.3.2.2 Independent Variables

The variation in the sustainable stormwater management plan quality scores was explained by measuring nine independent variables, which were categorized as follows: planning capacity, socio-economic, and stormwater risk variables. Table 3.6 shows a summary of variable descriptions and resources.

The data for planning capacity variables, which include plan adopted year, number of planners, and existence of consultants involved during the creation of a plan, were obtained from each jurisdiction's comprehensive plan, website, and individual contact with planning directors. Plan adopted year variable was measured by subtracting adopted/amended year by Year 2010. The number of planning department staff members was measured based on how many public officials contributed while writing a plan. The consultant variable was dichotomously measured by whether a jurisdiction employed private consultants during the plan adoption process.

The data related to socio-economic variables were all obtained from the 2000 US Census. Population density (the number of people per square mile), wealth (median household income), and education (the percentage of people obtaining a high school degree) were recorded for each jurisdiction.

Flood damage and the number of storm surge and flooding events data were gathered from the Spatial Hazard Events and Losses Database for the United States (SHELDUS version 13.1). Specifically, the flood damage measures the property damage caused by flooding and severe storm surge events during the study period in US dollars. Due to the skewness, the variable was log-transformed in order to approximate a Gaussian distribution (Brody et al., 2007). The number of severe storm surge events in each jurisdiction, which is a count variable ranging from 0 to 39, was measured by adding up the number of times that overland flow occurred during the study period (2000-2010). Impervious surfaces data was obtained from the USGS National Land Cover Database (NLCD) at 30 meter resolution. Landsat images were classified into eight major classes, and the percentage of developed land cover (NLCD Class 22 to 24) for each jurisdiction was calculated by ArcGIS with the Geospatial Modelling Environment (GME) (Beyer, 2010) extension.

Table 3.6. Concept Measurement

Variable	Description	Data source	Mean	S.D	Range
Dependent variable					
Plan quality scores	The total score of counties' five plan components	Plan coding protocol	22.55	5.57	7.56-34.31
Planning capacity variables					
Plan year	Plan adopted year minus 2010	Each jurisdiction's plan	-3.64	3.04	-10-0
Number of planners	Number of planners while creating a plan	Each jurisdiction's plan; Individual contacts	5.25	23.12	1-32
Consultant	Existence of consultants involved while creating a plan (1=yes, 0=no)	Each jurisdiction's plan; Individual contacts	0.57	0.50	0-1
Socio-economic variables					
Population density	Population density in each jurisdiction in 2000	US Census 2000 data	119.04	326.50	6.45-2,735.68
Wealth	Median household income in 2000	US Census 2000 data	43,913 .49	10,949. 83	29,882-74,167
Education	Percentage of population with a high school degree in 2000	US Census 2000 data	78.87	6.53	62.80-91.10
Stormwater risk variables					
Property damage (log)	Total property damage caused by flooding and severe storm events in each jurisdiction (2000-2010)	SHELDUS v13.1	11.09	5.26	0-17.91
Storm events	Number of flood/storm surge events in each jurisdiction (2000-2010)	SHELDUS v13.1	3.61	5.11	0-39
Impervious surfaces	Proportion of impervious land cover in 2006 (NLCD Class 22, 23, 24)	USGS	13.09	14.28	1.41-82.44

3.3.2.3 Validity and Reliability Threats

3.3.2.3.1 Validity Threats

Validity is the process of proving that the claims from the research are coming from the fact (Krippendorf, 2013). Namely, it refers to whether a finding has been accurately measured and interpreted in qualitative studies (Maxwell, 1996). Cook and Campbell (1979) categorized validity into four types: statistical conclusion validity, internal validity, construct validity, and external validity. This study addressed these four types of validity threats to produce stringent results and inferences.

Statistical conclusion validity is the degree of confidence in the statistical verification. That is, it determines whether statistics has been appropriately used to infer the correlation between independent and dependent variables (Shadish et al., 2002). Among the common threats to statistical conclusion validity, low statistical power can be problematic in this study. Low power occurs when a study has a relatively small sample size. Since this study uses only 76 local jurisdictions as the sample, the statistical conclusion validity may be threatened. Specifically, a single data or small number of outliers may bias the regression results. Therefore, it is important to examine the significance of each individual variable and identify factors that may affect the regression analysis (Brody, 2001). Considering the above fact, this study employed the regression blocking technique while conducting the multiple regression analyses, in order to alleviate the impact of each variable on the validity of statistical conclusion. Independent variables were grouped into three blocks and only the statistically significant variables on each model were chosen for the final fully-specified model. These approaches were previously applied by Brody (2001), Tang and Brody (2009), Tang et al. (2010), and Kang (2009) in their respective plan quality evaluations, where the sample size was relatively small compared to the number of independent variables.

Internal validity is used when we determine whether an experiment was well done insofar as avoiding confounding. Confounding here means that more than one independent variable may affect the dependent variable simultaneously (Indiana University Dictionary, 2013). Because there are a number of factors that may affect the plan quality, this study's internal validity could be threatened (Brody, 2001). Local comprehensive planning is a complex system that may influence by institutional, socio-economic, and physical factors. However, all factors cannot be considered in the regression model and even though they are included in a model, there can be other attributes that may explain the regression analysis. In addition, each individual may interpret the plan quality variations differently, and thus internal validity threat may remain in this study. Another significant internal validity threat may arise from the inconsistency of local plans' updated date. Local comprehensive plans that were adopted or amended between 2000 and 2010 have been chosen for this study. Hence, the evaluated plan quality may reveal disparate time period of planning efforts and stormwater management actions. However, independent variables that were used in this study may not reflect the planning efforts, capacities, or other contextual characteristic in the year that each plan has been updated. Thus, the dynamic process of planning cannot be captured precisely with the current regression model.

Construct validity refers to assessing the extent to which an instrument measures the construct as it was purposed to measure (Pedhazur & Schmelkin, 1991). In addition, it investigates the degree to which inferences from the variables can explain the theoretical constructs (Pedhazur & Schmelkin, 1991). Through a thorough literature review, the theoretical relationships between specific factors and plan quality score were explained and incorporated in the research model. One of the most important issues to increase the accuracy and consistency of plan content analysis is "measurement validity" (Norton, 2008). To improve the facial validity in measuring the theoretical concepts and build up the consensus of researchers, this study cautiously developed the uniform plan evaluation criteria with indicators equally weighted based on the various institutions' stormwater guidelines and previous plan coding protocol (Berke & Godschalk, 2009).

The adopted measurement procedure was repeatedly used in previous plan evaluation studies (Norton, 2008; Berke et al., 1996; Brody, 2003c; 2008; Tang et al., 2010).

External validity mainly refers to what extent a study's results can be generalized to other areas at other times. Different geographical, socio-economic, political, and governmental settings may influence differently on the plan quality score, and thus these variables should be considered cautiously to expand the outcome into other regions. However, the plan coding protocol and evaluation method that was used in this study can be applied to other areas. Furthermore, a comprehensive plan shows the vision of a community. Since we may not guarantee that all the policies and regulations within a local plan will be implemented in practice, higher plan quality scores on stormwater management will not always indicate that a community is managing stormwater more soundly or effectively.

3.3.2.3.2 Reliability Threats

Reliability refers to the consistency, repeatability, and stability of measurements (Shadish et al., 2002). To increase an inter-coder reliability and reduce personal bias in the judgement, the protocol and coding procedure were pretested by applying the test-retest approach within a small window of time (three-weeks) after the first evaluation. The final plan score was computed based on the second evaluation. The percent agreement score (the total number of agreements between the first and second evaluation divided by the total number of indicators) was about 92 percent. Miles and Huberman (1994) suggested that the percent agreement score (or coefficient) higher than 80 percent is considered to be acceptable, while Berke and Godschalk (2009) reviewed several plan evaluation studies and found that its range existed from 70 to 97 percent.

To examine the level of inter-item consistency and reliability, Cronbach's Alpha test, which assesses the degree to which a set of items (or indicators) are correlated as a group, was conducted in this study. The α values for each plan component and the entire plan quality are considered acceptable based on previous social science research (Nunnally, 1978; see Table 3.7).

Table 3.7. Inter-item Reliability (Cronbach's Alpha Test)

Plan component	Cronbach's alpha
Factual basis	0.676
Goals and objectives	0.618
Policies, tools, and strategies	0.797
Coordination and cooperation	0.708
Implementation	0.757
Total plan quality	0.874

3.3.3 Data Analysis

The data were analyzed in two phases. First, the sustainable stormwater management plan quality of 76 counties was assessed and calculated carefully by each plan component using the descriptive statistics. Second, the ordinary least squares (OLS) regression analysis was conducted to identify the linear associations between three types of independent variable and local sustainable stormwater management plan quality scores. Through the diagnostic procedures, there was no violation of OLS regression assumptions: model specification; outliers; multicollinearity; heteroskedasticity; and spatial autocorrelation. Specifically, the Ramsey Regression Equation Specification Error Test (RESET) revealed that the regression model was reliable (p=0.476), meaning that no linear combinations of the independent variables explain the dependent variable (Wooldridge, 2009). Multicollinearity was checked by looking at the Variance Inflation Factor (VIF) and values were less than 10 for all independent variables. The kurtosis and skewness values of the dependent variable were 2.6 and -0.1, which were less than 3 and 0.8, respectively. Skewness/Kurtosis tests for normality were also statistically insignificant at .05 level (p=0.648 and 0.948, respectively). This shows that the regression model does not have any normality issues. A Cook and Weisberg test for heteroskedasticity was statistically insignificant at .05 level (p=0.934), revealing that the residuals tend to have constant variances. A Moran's I test for spatial autocorrelation was statistically insignificant at .05 level (p=0.951) with the value of -0.009 (Figure 3.2). This ensures that the dependent variable's neighboring values are dissimilar and the regression model does not suffer from spatial autocorrelation (Highfield, 2012).

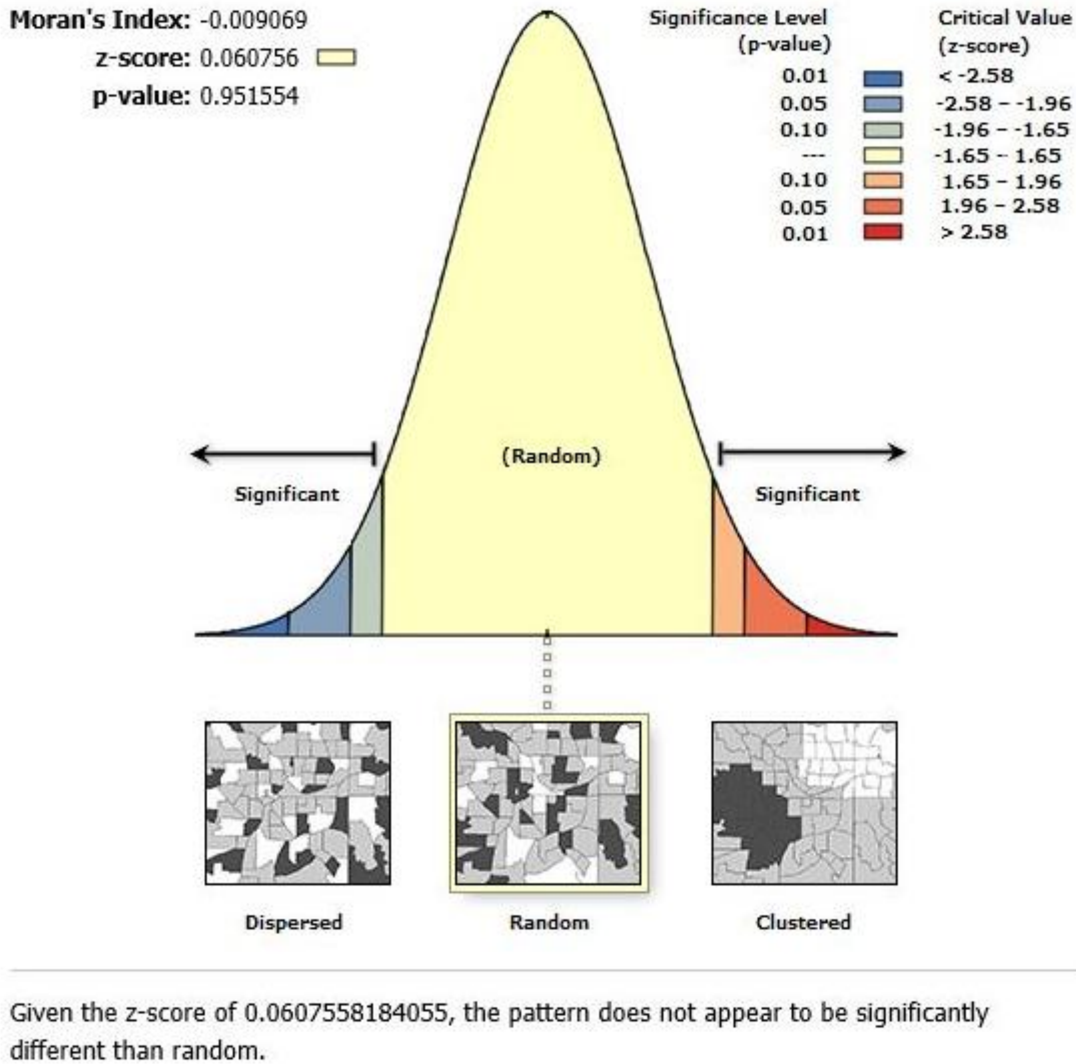

Figure 3.2. Moran's I Statistic for Plan Quality Scores

3.4 Results

3.4.1 Overall Sustainable Stormwater Management Plan Quality

Table 3.8 shows the descriptive statistics of overall plan quality as well as each plan component. The average score of the 76 counties' comprehensive plan was 22.55 out of 50, which signifies that the overall plan quality on stormwater management is weak with insufficient quantity and quality of planning tools. The distribution of plan quality score is presented graphically in Figure 3.3, showing that the variable is normally distributed. The scores range from 7.56 (Jefferson, WV) to 34.31 (Henrico, VA), meaning that large variations exist in plan quality among local governments within the Chesapeake Bay watershed (Figure 3.4). Total plan quality scores for each local jurisdiction are shown in Appendix B. Among the five plan components (score range: 0-10), the *factual basis* and *inter-jurisdictional coordination* components attained relatively high mean scores (5.57 and 5.21, respectively), implying that local plans tend to put emphasis on embracing comprehensive and specific background information in terms of sustainable stormwater management. In addition, local governments seem to recognize the importance of inter- and intra- governmental cooperation while dealing with stormwater related issues. The mean scores of the *goals and objectives* and *implementation* components were 4.85 and 4.07, respectively. Although their mean scores were quite low, the findings show that local planners as well as various stakeholders have fairly strong awareness towards achieving sustainable stormwater management concepts and endeavor actualizing into practice. The *policies, tools, and strategies* component received the lowest mean score of 2.86. This indicates that the existing action strategies not only have insufficiently coverage on sustainable stormwater management planning and techniques but also encompass limited abilities on developing and adopting specific stormwater related policies. The distribution of plan quality score is presented graphically in Figure 3.4.

Table 3.8. Descriptive Statistics for Total Plan Quality and Plan Components

Plan components	Total indicators	Minimum	Maximum	Mean	Median	Standard deviation
Factual basis	9	2.22	7.78	5.57	5.83	1.27
Goals and objectives	11	0.91	9.09	4.85	4.55	1.63
Inter-organizational coordination	7	1.43	7.86	5.21	5.00	1.50
Policies, tools, and strategies	29	0.69	5.34	2.86	2.59	1.07
Implementation	6	0.00	8.33	4.07	3.33	2.18
Total plan quality	62	7.56	34.31	22.55	22.39	5.57

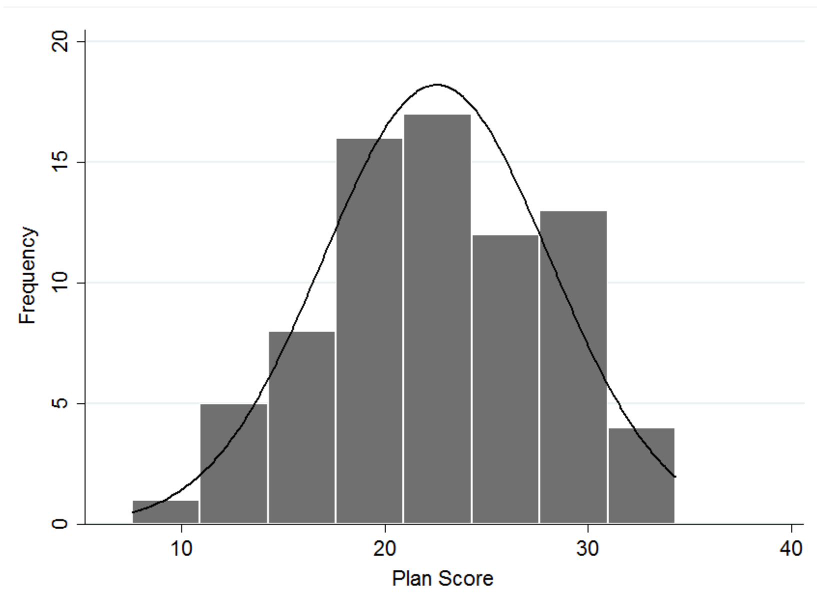

Figure 3.3. Histogram of Plan Quality Scores

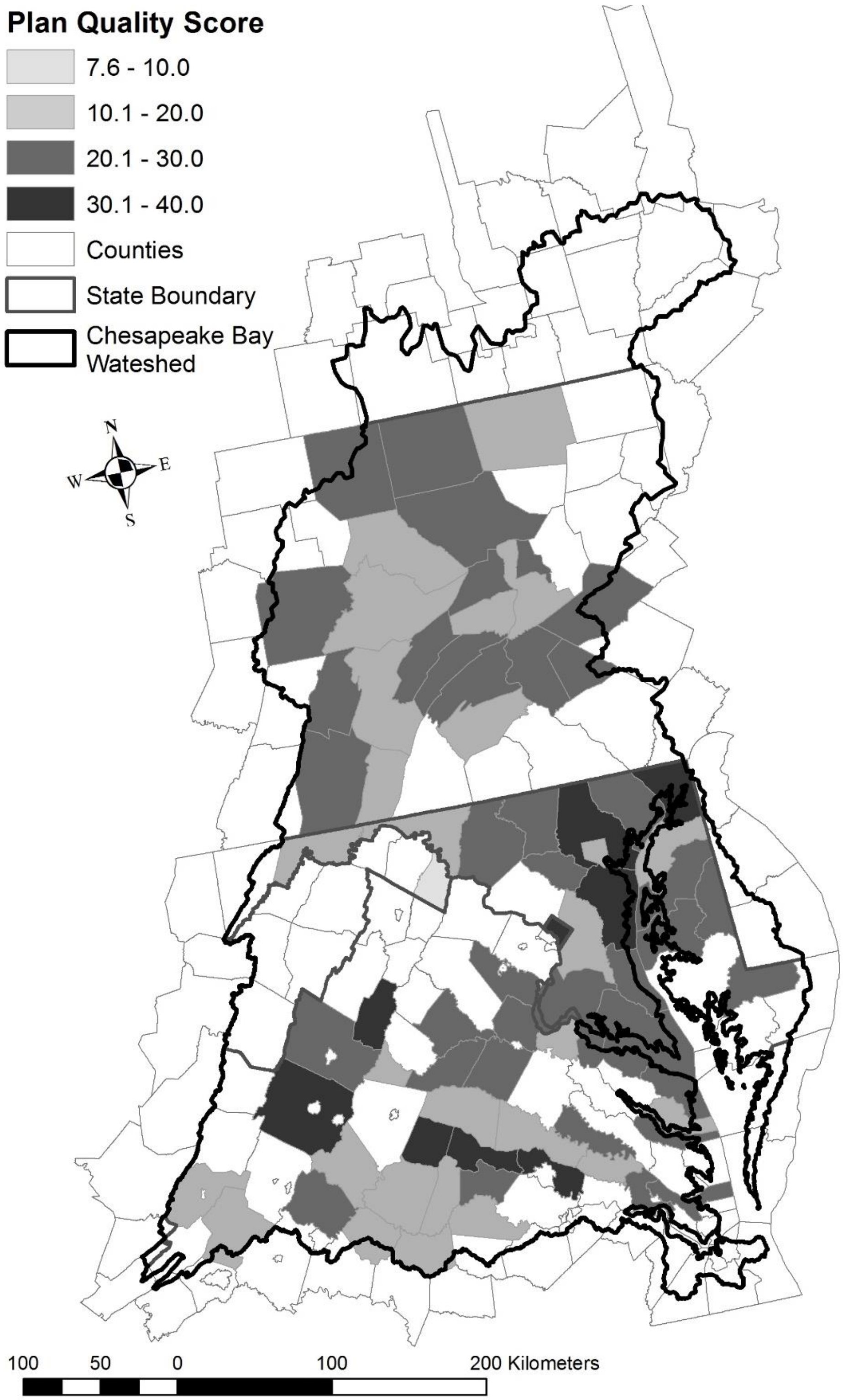

Figure 3.4. Plan Quality Scores of 76 Local Jurisdictions

3.4.2 Performance of Plan Components

3.4.2.1 Factual Basis

Regarding resources inventory, a relatively high percentage of plans described and mapped the inventory of environmental components, such as *wetlands, watersheds, water resources, vegetation/forests*, and *soils*. The breadth scores for these indicators ranged from 0.80 to 0.95 with the depth scores ranging from 0.79 to 0.84, revealing that most local jurisdictions are likely to mention key environmental features within their plans with detailed description. However, *local climate information* was not frequently mentioned and poorly portrayed with the breadth and depth scores of 0.32 and 0.43, respectively.

A majority of plans in the sample delivered information related to human impacts, such as *current/future land uses, population projection*, and *stormwater infrastructure services*. Specifically, all local jurisdictions provided *the inventory of current and future land uses,* while their quality of information varied. Since stormwater runoff heavily relies on the development pattern, accurate estimation of population as well as the needs for stormwater infrastructure should be included within a plan. Most plans identified *demographic* and *stormwater infrastructure information,* but there was a lack of data or maps projecting future population growth as well as limited schemes for stormwater infrastructure expansion. Sixty-one percent of plans identified the inventory of *water pollution types and sources* and only a few plans (22 percent) addressed impervious surface density with the absence of specific information.

In summary, indicators' performances were relatively high for conventional environmental components and fundamental elements that were typically included in most comprehensive plans. Local jurisdictions, however, still have weak understanding on issues that tend to directly relate to stormwater runoff (Figure 3.5).

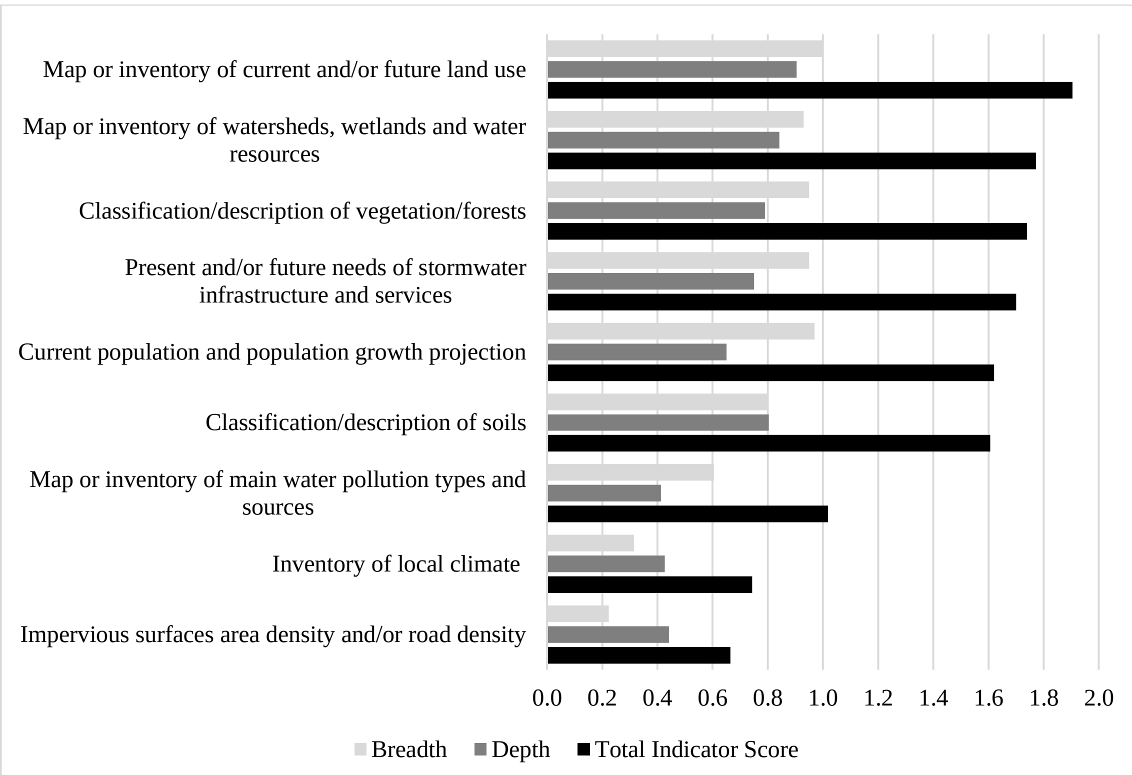

Figure 3.5. Indicator Performance for the Factual Basis Component

3.4.2.2 Goals and Objectives

Regarding general features of the goals and objectives component, a high percentage of local plans' goals were clearly specified (96 percent), while objectives were mostly not measurable (24 percent; Figure 3.6). The majority of plans encompassed broad goals such as *protecting natural processes and functions*, *encouraging open spaces*, and *improving water quality*. In contrast, a comparatively small number of plans specified their goals and objectives incorporating the key principles of sustainable stormwater management, such as *maintain/improve stormwater management facilities* (45 percent), *control/reduce stormwater runoff or flood* (36 percent), and *encourage public participation* (33 percent). Furthermore, three indicators (*minimize impervious surfaces from development, promote low impact development*, and *establish adequate funding for stormwater management*) were mentioned by less than 20 percent of the sampled plans. The findings suggest that local jurisdictions are more likely to incorporate general and comprehensive goals, while less attention was paid to integrating stormwater management issues. Thus, it made it difficult to incorporate specific policies and planning tools focusing on stormwater management (Brody, 2008).

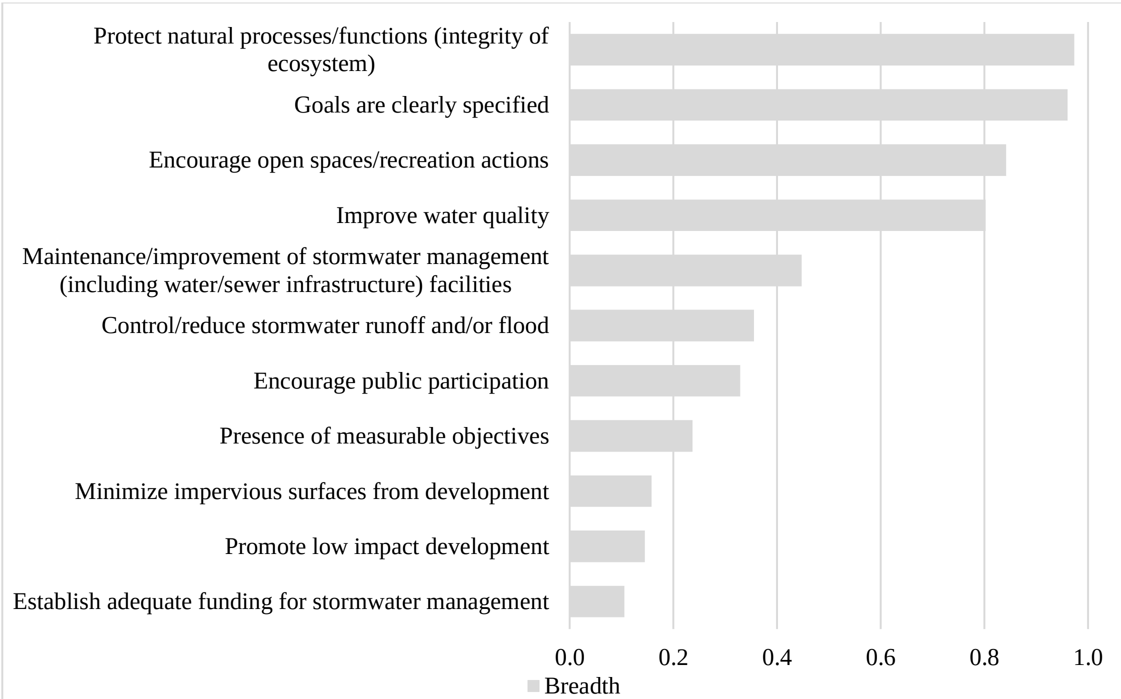

Figure 3.6. Indicator Performance for the Goals and Objectives Component

3.4.2.3 Inter-organizational Coordination and Capabilities

As shown in Figure 3.7, every indicator in this component scored higher than 1.00, revealing that the overall cooperation system within and between jurisdictions is well established in terms of sharing and protecting environmental resources. In particular, various organizations, stakeholders, and jurisdictions are identified concretely. A number of plans have mentioned that coordination is necessary between neighborhood jurisdictions, private sectors, and higher levels of governments, such as federal and state agencies, but they did not fully suggest a precise scheme or plan for collaboration. In addition, the information with regard to the *coordination within jurisdiction* was not copiously specified, while half of the local jurisdictions stated the statement in their plans. Approximately 73 percent of local jurisdictions mentioned *integrating other environmental plans, programs, and regulations in the region*, such as state stormwater management plans, acts, and design manuals, as well as watershed implementation plans, into local planning structure. Finally, fifty percent of the plans *designated financial resources* to engage diverse stakeholders in managing stormwater runoff with a moderate commitment to achieve it.

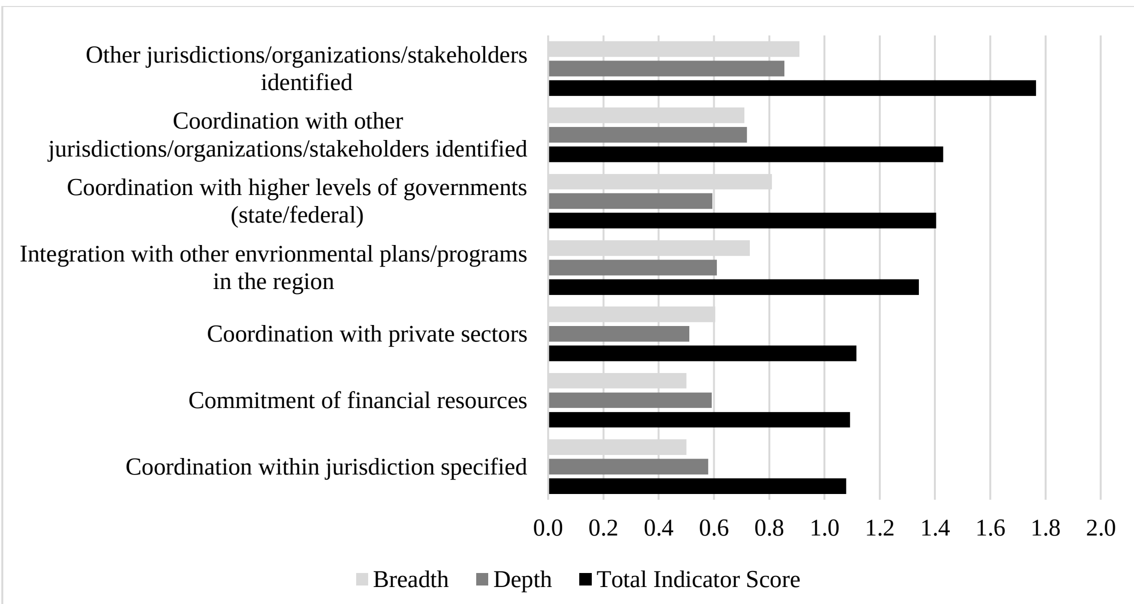

Figure 3.7. Indicator Performance for the Inter-organizational Coordination and Capabilities Component

3.4.2.4 Policies, Tools, and Strategies

Large variations existed between the indicators' score in this component (Figure 3.8). Among six representative categories, the total average indicator score of the on-site control and structural tools was 1.08. Most local governments (93 percent) have given much attention in adopting *innovative stormwater management practices*, such as BMPs, LID techniques, and green infrastructures, while their information was not thoroughly addressed with the depth score of 0.68. One of the reasons for the high adoption can be due to the active financial and technical supports from the state governments on implementing BMPs and LID practices (Fu & Tang, 2013). In contrast, very few plans discussed policies regarding *green buildings* (25 percent) and *constructed wetlands* (7 percent). However, when they were mentioned in a plan, strategies were described modestly (Depth: 0.61 and 0.70, respectively).

An indicator that is comprised within the general policy component received the highest total indicator score of 1.63. A majority of plans (95 percent) mentioned that policies should be *consistent with other plans, ordinances, and regulations*. However, the depth coverage was relatively low with a score of 0.68. Although several local plans discussed that stormwater should be managed consistently with the federal, state, and local programs or regulations, such as NPDES permit program, state stormwater management act, and local site and subdivision regulation, states are not likely to mandatorily require stormwater management elements included within a comprehensive plan. Thus, policies tend to be described in vague terms.

With regard to the regulatory tools, environmental regulations that were often employed in the past, such as *setbacks/buffer zones* and r*estrictions on local vegetation and forest removal*, received comparatively high total indicator scores. However, land use related regulations, such as *land use restriction near sensitive water bodies*, *innovative design for new- and re-developments*, and *urban service/growth boundaries*, were not amply adopted by the plans sampled. These findings correspond with previous plan quality studies that have measured environmental action plans and policies (Brody, 2008; Fu & Tang, 2013). A bulk of jurisdictions were not willing to address regulatory tools that were specified for managing stormwater runoff quality and quantity. Less than 45 percent of jurisdictions adopted these policies and the qualities of detail coverage scored an average of 0.54. Most counties adjacent to the Chesapeake Bay are more likely to mention specific stormwater-related regulations, including *Total Maximum Daily Load (TMDL), minimum pipe size, erosion and sediment control, usage of pesticides and fertilizers*, and *monitoring of water quantity and quality*, within their local plans compared to inland communities. Overall, although the breadth score was quite low for the regulatory tools, the depth score indicated that local plans delivered them in good detail, meaning that more opportunities lie in these policies to be improved when they are mentioned.

The average total indicator score of the incentive tools was the lowest among six representative categories; 0.92. Two traditional land use planning tools (*clustering development* (78 percent) and *transfer of development rights* (63 percent)) were widely mentioned in local plans compared to other three policies. Thirty-two percent of the sample brought up *density bonuses*, but plans rarely addressed *stormwater impact fees* and *stormwater fee discounts* (9 and 7 percent, respectively). All five policies' depth scores were near 0.50, representing that specific information was not given and terms were not stringent enough to encourage the implementation.

Within four land acquisition tools, *open space preservation* (93 percent) and *conservation easement* (88 percent) indicators were frequently mentioned in local plans. About half of the plans (47 percent) stated *other land acquisition techniques*, which include policies and tools, such as resource conservation zoning, inclusionary zoning, land banking programs, amendment of conservation zoning districts, partnership with local land trusts, and weighting and ranking of environmentally sensitive lands. Notably, however, the term *fee simple purchases*, which is a form often represented in a plan as a land and property acquisition technique, was seldom addressed in the sample (11 percent). The indicators' depth scores ranged from 0.50 to 0.60 in this category.

Awareness tools are one of the most important non-structural measures to help various stakeholders recognize the importance and build an understanding of sustainable stormwater management concepts. While *education and outreach programs* for residents have been emphasized by approximately three quarters of the sample, *training and technical assistances* for government officials received less attention (50 percent). Only 16 percent of jurisdictions included developing or maintaining maps of areas subject to flood hazards (floodplains) or stormwater runoff. The qualities of depth scores for all three indicators ranged similarly with the land acquisition tools, which were between

0.57 and 0.64. This means that words of policy statements were vaguely described rather than firmly committed and specific information was not greatly covered.

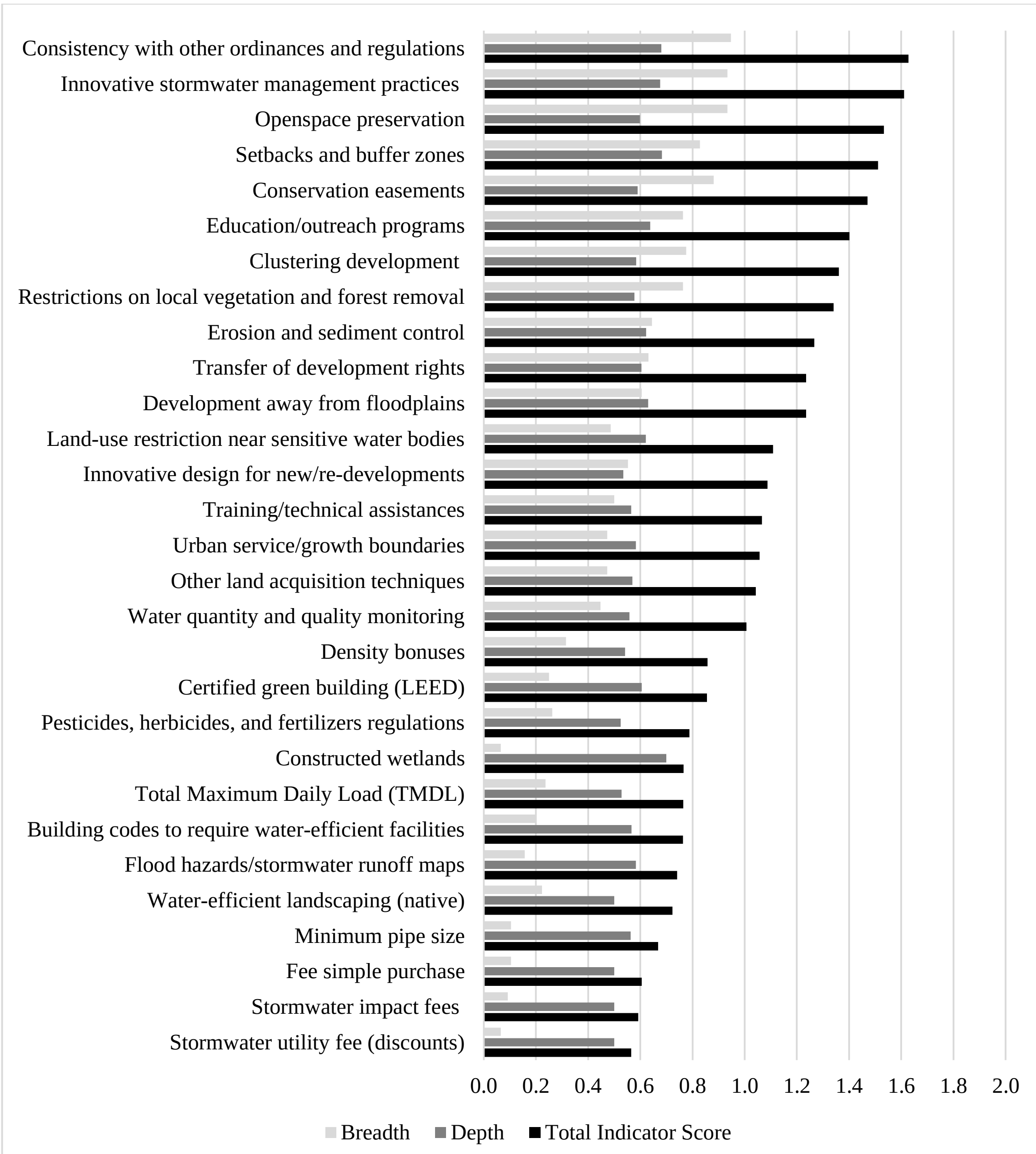

Figure 3.8. Indicator Performance for the Policies, Tools, and Strategies Component

3.4.2.5 Implementation

The implementation component seeks to measure whether a local jurisdiction has sufficient capabilities to implement its plan rather than determine if plan indicators are realized after the adoption (Brody, 2008). As illustrated in Figure 3.9, a comparatively high percentage of local jurisdictions have incorporated the indicators that are essential for implementing a plan (*regular plan updates and assessments*, *responsibilities for actions*, and *identification of financial and technical support*) except *providing a clear timeline*. Their relatively low depth scores, however, imply that plans had limited details. Although only 43 percent of plans presented a clear timeline for implementation, the depth score was 0.88, revealing that it provides the thorough information if stated in a plan. Unfortunately, localities are less likely to focus on managing stormwater runoff compared to the essentials of implementing a plan, and thus required to prepare more efforts for its implementation.

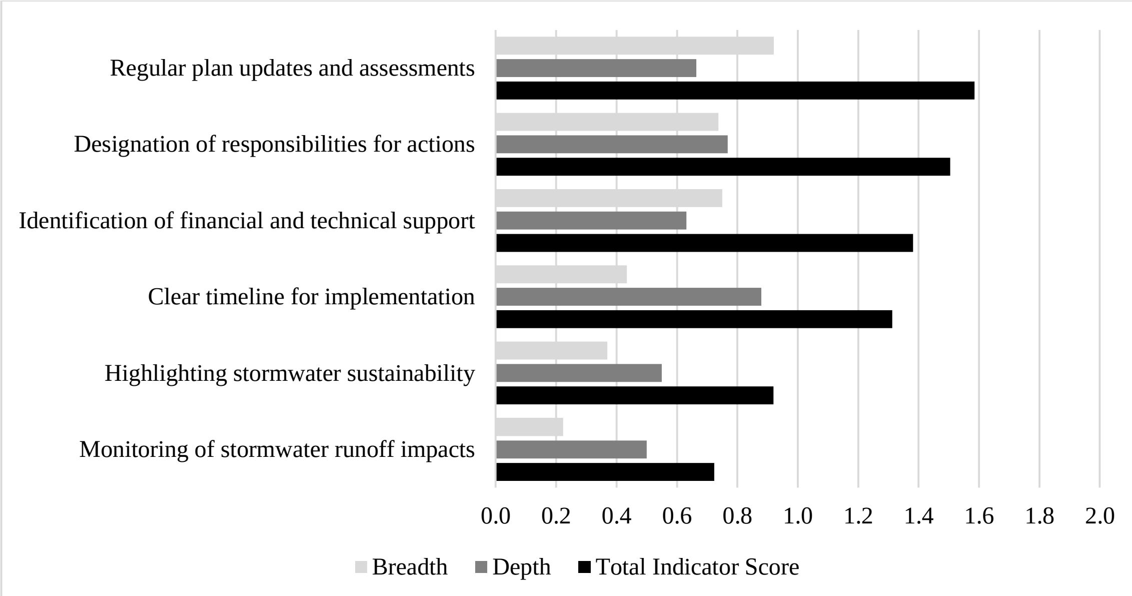

Figure 3.9. Indicator Performance for the Implementation Component

3.4.3 Explaining the Variation in Plan Quality Score

Results from multivariate regression analysis identify which factors are significantly associated with the quality of sustainable stormwater management plans (Table 3.9). Variables were analyzed by three suites of groups since the sample size was relatively small compared to the number of independent variables (N=76). Statistically significant variables in each of three models were then chosen for the fully specified model by using the regression blocking method. The variance of the dependent variable was explained the most by planning capacity variables (36 percent), followed by socio-economic variables (20 percent) and stormwater risk variables (13 percent).

The results of Model 1 (planning capacity variables) suggest that the plan adopted year and the number of planners make statistically significant contributions to sustainable stormwater management plan quality. In particular, both variables had a positive impact on plan quality ($p<0.05$), meaning that local plans that have recently updated and more planners engaged while drafting a plan have better quality in terms of integrating sustainable stormwater management principles. The results coincided with the previous plan quality studies' findings that up-to-date plans are more likely to mention diverse action strategies and policies, and thus generate higher-quality plans (Brody et al., 2004; 2006; Tang, 2008). In addition, plans can be more systematically and effectively produced and implemented when larger numbers of planning staff are involved during the planning process with high commitment. (Brody, 2003a, 2008). However, local plans with consultants' involvement during the adoption process brought insignificant and negative impact on plan quality. The most persuasive explanation for this result is that local jurisdictions with limited human resources and personnel were likely to hire consultants while creating a plan, and thus they had relatively weak planning capacities compared to other jurisdictions that have not hired consultants. In addition, the correlation between the number of planners and the involvement of consultants while creating a plan was negative (Appendix A). The result of the multiple regression analysis also suggested that consultants' involvement was not effective in developing stormwater-driven plans even though the effect was statistically insignificant.

In Model 2 (socioeconomic variables), the median household income appeared as a statistically significant factor in explaining the plan quality ($p<0.05$). The finding suggests that local jurisdictions with higher median income have a greater motivation to integrate sustainable stormwater management principles in their plans. Population density also had a positive impact on plan quality, but it did not show significance at the 0.05 level. Although past studies (Berke et al., 1996; Brody, 2003a; Brody et al., 2006; Tang & Brody, 2009; Tang et al., 2010) have identified that highly populated areas are more likely to disturb environmental conditions and thus the population density is negatively associated with plan quality, the empirical results in this study did not discover any statistical evidence that higher population density may result in higher sustainable stormwater management plan quality. Since population density and education (the percentage of population with a high-school degree) had a high correlation (0.630) and their theoretical relationship with plan quality is parallel, the education variable was dropped in the model analysis.

Model 3 (sotrmwater risk variables) revealed that the number of flood and severe storm events and the percentage of impervious cover were statistically significant predictors ($p<0.05$) of local plan quality. Specifically, jurisdictions that have experienced more historical flooding events had lower plan quality, while a percentage increase of impervious surface cover was positively associated with sustainable stormwater management plan quality as expected. The association between property damage from flooding/storm surge events and local sustainable stormwater management plan quality was not statistically significant. However, it showed that an increase in flooding damage leads to an increase in plan quality.

A fully specified model (Model 4) was constructed in this study by including the selected five variables that were statistically significant in each model to further examine how the factors explain the variance of plan quality. The five variables are: plan adopted year, number of planners, median household income, number of flooding/storm surge events, and the percentage of impervious surface. The model explained approximately 46 percent of the variation in local plan quality. Local governments that have recently adopted their plans received higher plan quality in addressing sustainable stormwater management concepts ($p<0.01$). In particular, the plan adopted year was the most powerful predictor of plan quality score. The number of flooding and severe storm events remained as a powerful predictor by negatively influencing the local plan quality ($p<0.05$). In other words, local jurisdictions that have experienced more historical flooding/storm surge events are likely to have lower quality of plans associated with sustainable stormwater management concepts. This result was the opposite of the initial hypothesis that jurisdictions with more hazard experiences will produce better quality plans due to the increased institutional capabilities in coping with past experiences. Moreover, a percentage increase in impervious cover remained a positive impact on local sustainable stormwater management plan quality ($p<0.1$). The number of planners and median household income suggested positive relationships with sustainable stormwater management plan quality even though they were not significant predictors for plan quality at the 0.1 level of significance.

Table 3.9. Models Explaining Sustainable Stormwater Management Plan Quality

	Model 1	Model 2	Model 3	Model 4
	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)
Planning capacity variables				
Plan year	**0.9691*** (0.1788)**			**0.8997*** (0.1684)**
Number of planners	**0.2443** (0.1126)**			0.1440 (0.1228)
Consultants	-0.4580 (1.0780)			
Socio-economic variables				
Population density		0.0005 (0.0019)		
Median household income (1/1000)		**0.1565** (0.0712)**		0.0707 (0.0519)
Stormwater risk variables				
Property damage (log)			0.1395 (0.1321)	
Flooding events			**-0.3408** (0.1326)**	**-0.2272** (0.1000)**
Impervious surfaces			**0.0893** (0.0442)**	**0.0644* (0.0378)**
Constant	25.0556*** (1.3638)	8.2663 (7.8647)	21.0591*** (1.4524)	21.9407*** (2.4089)
N	76	76	76	76
F ratio	13.77	4.24	3.63	11.65
Probability > F	0.0000	0.0081	0.0170	0.0000
R^2	0.3646	0.1502	0.1314	0.4542
Adj. R^2	0.3382	0.1148	0.0952	0.4153
Root Mean Square Error	4.5288	5.2378	5.2952	4.2570

Notes: D.V.: plan quality score; *: significant at .1 level; **: significant at .05 level; ***: significant at .01 level

3.5 Discussion and Policy Implications

Through the descriptive analysis, this study identified that local governments within the Chesapeake Bay watershed have not sufficiently integrated the principles of sustainable stormwater management into their comprehensive plans. The average plan quality score was 22.55 out of 50. There is a significant lack of planning efforts and limited awareness of local planners to integrate the key principles of sustainable stormwater management into the existing planning framework. Although several state stormwater management acts within the watershed regions encouraged local municipalities to adopt and enforce stormwater management regulations, adopting consistent stormwater management ordinances and regulations were not mandatory to local governments. Thus, local jurisdictions had relatively low motivation and unclear awareness to take actions in controlling stormwater runoff in a sustainable manner. Among the three states (excluding West Virginia and District of Columbia), Maryland had the highest average plan quality scores. Even though several factors such as population, wealth, and the distance from the bay may explain this result, the impact of the 1992 Economic Growth, Resource Protection, and Planning Act can be one of the most significant contributors that improved the overall plan quality of Maryland associated with sustainable stormwater management. Since the act pushed localities to follow state-wide policies for land use planning and resource protection, the majority of local comprehensive plans in Maryland embraced goals and action strategies regarding overall ecosystem management and resource protection, which are the key components of sustainable stormwater management principles. This verifies that top-down approaches provide a powerful motivation for local communities to adopt certain policies even though the issues are not faced in front at the moment. In addition, while local comprehensive plans generally mentioned flooding and water quality issues, the term, “stormwater,” was not addressed considerably. Since problems triggered from stormwater runoff have not been serious in the past and the integration of sustainable stormwater management concepts into the local comprehensive plan is a newly developing perception, it is not surprising for local jurisdictions to have relatively low plan quality scores associated with sustainable stormwater management. The findings also correspond to the results of past research that evaluated local ecosystem, environmental, and flood mitigation principles and policies, which were not prioritized in local comprehensive plans (Brody, 2003a; Kang, 2009; Tang, 2009). To further increase the awareness and understanding of sustainable stormwater management to local decision makers, plans should assess and show the potential adverse effects that may triggered from inadequate stormwater management. Also, using various awareness instruments such as training workshops, public meetings, printed materials, school education programs, and web interfaces may increase the public awareness to foster developers and residents in adopting sustainable stormwater management practices.

Regarding the indicators’ performance, local jurisdictions in the study area produced relatively a strong factual basis in their local comprehensive plans associated with sustainable stormwater management principles (average score: 5.57). Based on a solid factual basis, each local government may develop specific and concrete goals and action strategies. However, local plans were generally weak in adopting detailed policies and strategies that addressed controlling and managing stormwater. In particular, the policies, tools, and strategies component received the lowest score among the five components (average score: 2.86). This can be explained because the indicators that were examined for the factual basis component embraced the broad concepts of sustainable stormwater management, which include ecosystem management, hazard reduction, and climate change. Thus, indicators were likely to include more general environmental elements rather than specific inventories that are directly related to controlling stormwater runoff. To formulate a stringent stormwater management policy, localities should not only have up-to-date information and adequate projections, but also enhance the information basis regarding current and future climate conditions, financial resources, and stormwater related issues, such as water pollution types and sources, and the density of impervious surfaces. In addition, although stormwater is considered as a cross-boundary or regional issue, local governments should manage and integrate the information at the local level to develop effective action strategies. To keep abreast of the trends in relevant stormwater management information, the capacity of institutions must also be enhanced by cooperating with various departments as well as through continuous targeted workshops from water professionals/experts.

The goals and objectives regarding sustainable stormwater management were set relatively well (average score: 4.85). However, there was a large variation among the indicators. While broad and long-term goals and objectives were often mentioned within the sample, goals that are explicitly associated with the stormwater management were rarely adopted. The trend was consistent with the factual basis component. In particular, goals and objectives related to water quantity issues were paid less attention compared to water quality issues. Local comprehensive plans thus need to create visions, goals, and objectives more focusing on controlling the stormwater runoff volume and including up-to-date stormwater management techniques (ex. BMPs and LID techniques) through periodic review and update. Moreover, clear, specific, and measurable objectives should be presented together.

Inter-organizational coordination and capabilities were well recognized by local comprehensive plans (average score: 5.21). Because of to the Chesapeake Bay Agreement of 1983 and the Chesapeake Bay Program partnership, all states within the study area have developed their own stormwater management acts and regulations and collaborated with each other to restore and preserve the bay and its watersheds. As the findings show, the total indicator score for all indicators was higher than the score of 1, revealing that local jurisdictions were already aware of the importance of collaborative efforts between adjacent jurisdictions, higher levels of governments, and other various stakeholders on solving the cross-boundary issue. However, there are still limited regional planning efforts to drive local governments to adopt collaboration instruments into their planning policies. To establish more realistic goals and policies for an effective implementation, municipalities within a county should first participate actively. The lack of intra-jurisdictional coordination between municipalities and departments as well as commitment to the financial resources are barriers for efficient stormwater management, and thus more effective collaborative efforts are necessary at the local level. Limited capacity of institutions and knowledge of department staff members has been known to be a large obstacle for the implementation of efficient stormwater management (Brown et al., 2001). For instance, Stahre (2002) and Stahre and Geldof (2003) emphasized that BMPs and LID techniques can be achieved through dynamic involvement and the cooperation of various city departments as well as the active participation of the public. Cettner et al. (2013) highlighted that the role of water professionals is crucial during the planning process to effectively manage stormwater. Since the current planning system does not incorporate the commitment of staff members in the water department, it is challenging to design sustainable stormwater management prior to developing a plan. By embracing planning approaches and water related engineering approaches, more sustainable stormwater perspectives can be applied before any new or redevelopment processes (Cettner et al., 2013). Therefore, given the fact that the comprehensive plan is developed by the lead of local planners, cooperation especially with the water departments and utilities are highly recommended.

The policies, tools, and strategies component was the weakest element in the sampled plans. Jurisdictions should expand both structural and non-structural planning toolkits containing more directive and specific strategies toward to stormwater management. Regarding structural measures, the term, “BMPs,” was frequently mentioned in the existing local plans, while tools such as certifying green buildings and developing constructed wetlands were often omitted. Local jurisdictions often used the terms related to innovative stormwater management tools due to the federal and state governments’ enforcement as well as financial and technical supports. However, compared to the usage of BMPs, LIDs and green infrastructures were not often revealed within the sampled plans. In addition, green buildings have been identified to provide positive impact on minimizing the amount of stormwater runoff by constructing green roofs and rainwater harvesting systems. Also, cost-effective traditional measures such as constructed wetlands and detention/retention ponds have been continuously adopted by a number of localities due to its efficiency. Thus, local planners should adopt all of the planning approaches available and link to planning policies.

With regard to non-structural measures, the findings of this study identified that current local plans highly relied on traditional land use regulations and acquisition tools such as setbacks and buffer zones, land use restrictions, open space preservation, and conservation easements for managing stormwater. Newly emerging approaches (e.g., innovative design for new- and re-development projects, water efficient building codes, etc.) as well as regulations directly related to controlling stormwater quantity and quality (e.g., TMDL, minimum pipe size, pest control, etc.) were not fully considered in local plans. The results also indicated that several incentive tools were poorly adopted within the sampled plans. Since these tools may voluntarily allow stakeholders to put the principles of sustainable stormwater management into practice, local jurisdictions should pay more attention to employing newly emerging tools (e.g., stormwater impact fees and stormwater utility fees) rather than relying heavily on the conventional tools (e.g., clustering development and transfer/purchase of development rights). In addition, although awareness tools have been relatively well mentioned in local plans, unclear duties for trans-boundary stormwater issue at all levels and the lack of national commitment to control stormwater discharges are still large barriers to implementing sound sustainable stormwater management planning. By providing more incentives and financial supports, higher levels of government should encourage localities to give more weight on preparing for damage associated with stormwater runoff and enhance awareness of integrating sustainable stormwater management principles into local action strategies.

Studies have identified that there is a high correlation between the implementation plan component and the degree of plan implementation (Brody & Highfield, 2005). Many local jurisdictions in the sample, however, failed to sufficiently incorporate the implementation mechanisms (average score: 4.07). Without robust and dynamic implementation and monitoring mechanisms, policies will be inefficacious in the real world. While many jurisdictions have frequently referred to general implementation indicators (e.g., regular plan updates and assessments, designation of responsibilities for actions, and identification of financial and technical supports), sustainable stormwater management was not highlighted as priority in implementation and, stormwater runoff monitoring system was inadequately adopted in local plans. To better improve the implementation capabilities, local jurisdictions should localize the cross-boundary stormwater issues and establish a systematic monitoring program to continuously maintain the effectiveness of plan contents with up-to-date information. For local planners to be proactive rather than reactive, an adaptive management should be melted into the existing planning framework (Tang, 2008). Thus, stormwater runoff quantity and quality ought to be continuously monitored to better reflect the changing environmental conditions. Moreover, a clear timeline, which illustrates the detailed policy implementation information, must be provided in local comprehensive plans to effectively carry out the action strategies into practice. In addition, as discussed in the above, public awareness should be primarily considered to implement and apply specific policies since increased awareness will allow residents to recognize the crucial role of stormwater management and build the public consensus more efficiently during the planning process (Kang, 2009).

The findings from multiple regression analysis also suggested important local planning implications by identifying which factors influence local plan quality associated with sustainable stormwater management. Within the planning capacity variables, plan adopted/amended year was the most significant predictor contributing to a higher plan quality score. This verified the initial hypothesis that more recent and regularly updated plans may incorporate the latest information and circumstances, and thus help local planners to reflect up-to-date techniques within the action strategies. Larger numbers of planners while writing a plan led to the production of higher quality plans integrating the principles of sustainable stormwater management. The existence of more qualified planners not only means better technical and planning can be inputted during the adoption/amending process, but also allows local governments to take proactive actions in anticipating damage from stormwater runoff and managing stormwater more effectively (Brody et al., 2006). Small jurisdictions with limited qualified planners were likely to hire private consultants while creating a comprehensive plan. However, the presence of consultants decreased the plan quality score even though the result was statistically insignificant. This revealed that overall plan quality especially with regard to sustainable stormwater management will be weak without adequate contributions from local qualified planners.

For socio-economic variables, sustainable stormwater management plan quality was higher in jurisdictions with wealthier residents. This result corresponded with previous research that wealthier jurisdictions may have greater awareness and financial capacity for conserving environmental features and thus produce higher quality plans (Brody et al., 2004). Moreover, jurisdictions in Maryland had the highest average median household income ($51,727) followed by Virginia ($41,172) and Pennsylvania ($35,543) and this trend stayed abreast with the average plan quality scores (MD: 24.07; VA: 22.73; PA: 21.78).

Within the stormwater risk variables, jurisdictions that have experienced more historical flooding/storm surge events adopted lower quality plans associated with sustainable stormwater management. This result was contradictory with some past studies (Brody et al., 2008) and the initial hypothesis of this study that frequent exposure to natural hazards including flooding and storm surge events may motivate local planners to adopt higher quality plans. That is because local communities have better understanding on their vulnerabilities to previous hazard damages stoked by stormwater runoff; thus, they tend to have stronger preparedness plans and policies after recurrent events. However, the relationship of two variables in this study can be explained by three major reasons. First, there were several rural localities in the sample. Since rural areas have limited planning capacities and resources, these communities may not correspond relatively well compared to urbanized jurisdictions even after the frequent storm events. Also, even though there is a state stormwater management regulation, small communities tend to meet the minimum requirements rather than building concrete local preparedness policies. Second, integrating the sustainable stormwater management principles into local comprehensive plans cannot be done within a short-term and should reflect wide-ranging issues including ecosystem, flooding, and sustainability. Some jurisdictions, however, attempted to solve the concerns immediately without addressing long-range preparedness planning after the storm events; and thus, contributed to fostering negative relationship between two variables. Third, as shown in the result of Model 3, property damage was positively associated with plan quality score even though it was statistically insignificant. This result fragmentarily indicates that local jurisdictions that had higher historical property damage from flooding/storm surge events may adopt a plan of better quality. Because the property damage and the number of flooding events was not highly correlated, this relationship indicates that jurisdictions with frequent experiences of flood events did not always have huge damage caused by flooding or overflow. While the results of these two variables have shown a different direction to plan quality, local decision makers should consider both factors seriously and reflect effectively on the past consequences. On the other hand, greater percentages of impervious surfaces cover led to a stronger plan quality. Local jurisdictions with high developed and populated areas often cover more impervious surfaces. Thus, their fruitful financial and technical resources allow local plans to better integrate adequate sustainable stormwater management principles. In addition, more regulations with regard to Municipal Separate Storm Sewer System (MS4) may exist in urbanized areas, which will promote local comprehensive plans to incorporate more numbers and detailed policies toward to stormwater management. However, since urbanized jurisdictions were more likely to be vulnerable from stormwater runoff, local planners should adopt policies and strategies that can incorporate innovative structural and on-site source control techniques such as BMPs and LID practices. Unfortunately, most people have insufficient knowledge of LID practices even today. Thus, encouraging public participation and social learning environments during the planning process may improve the quality of plans as well as the overall awareness of stakeholders (Brody, 2003a). Local governments should prepare up-to-date maps of areas subject to frequent flash flooding and provide sufficient information about the adverse impacts of urban runoff, impacts that could affect a society with regard to environmental, economic, and social aspects. Awareness of stormwater management could be increased by conducting several public education programs and various types of training strategies such as organizing training workshops and public hearings/meetings, creating websites that include fundamental knowledge of LIDs and providing printed/video materials (Brody et al., 2010). In addition, providing educational signs next to BMPs and LID practices will help enable people to acknowledge the different types and attributes of specific sustainable stormwater management practices. The increased awareness should facilitate a local government to act on and plan for stormwater management. Also, governments should provide and verify that constructing LID techniques will benefit developers and constructors by conducting experimental studies.

3.6 Conclusions

This study examined whether local jurisdictions within the Chesapeake Bay watershed have successfully integrated the principles of sustainable stormwater management into their local comprehensive plans and which factors significantly contribute to the plan quality. Evaluating the local plans through the developed plan coding protocol provided insights into which jurisdictions were committed to pursuing sustainable stormwater management and what measures were primarily taken to manage stormwater in a sustainable manner. In addition, statistical analysis identified which specific factors stimulate jurisdictions to adopt high quality sustainable stormwater management plans and how local planners should use their planning capacities, resources, and tools to strategically control stormwater runoff.

This study provided evidence that local plan quality can be driven by the capacities of local planning, built environments, and past flooding experiences. In specific, planners should regularly update their comprehensive plans and put significant efforts during the planning process since those planning capacities play an important role in enhancing the quality of local plans. Although urbanized areas tend to create higher quality plans due to relatively affluent technical and personnel resources, they also are more vulnerable to excessive runoff because of higher percentage of impervious surfaces. Thus, their development policies and decisions should be carefully made in choosing where to develop and protect in order to alleviate the adverse impacts from flash flooding. Awareness and understanding of stormwater management should be also raised by learning from historical hazard experiences not only to build communities more resilient toward to excessive runoffs, but also to produce higher-quality plan.

Though this study provided some valuable findings, several limitations still exist in examining the topic of sustainable stormwater management plan quality and generalizing the findings into other relevant plan evaluation studies. Further research should be pursued on several fronts.

First, the sample size of 76 in this study is relatively small for making statistical conclusions due to the limited statistical power. To include more variables in the same model and thoroughly interpret the findings with better confidence from the statistical analysis, sample sizes should be increased by embracing more diverse localities. Since the samples in this study were mostly local counties, adding municipalities within the Chesapeake Bay watershed region will not only enlarge the sample size but also allow for comparison of counties and municipalities' plan quality associated with sustainable stormwater management.

Second, although plan indicators that were employed for the sustainable stormwater management plan quality evaluation have been carefully chosen based on the stormwater manuals, guidelines, and previous plan evaluation studies, additional opinions from the stormwater professionals or water department officials will help develop more in-depth and comprehensive evaluation criteria and processes. Concrete reviews from those experts will also enable indicators to be prioritized during the evaluation process and thus further develop the existing plan coding protocol.

Third, only local plans that have been adopted or amended between 2000 and 2010 were selected for the evaluation. Since local comprehensive plans assessed in this study were relatively outdated, newly emerging techniques or practices may not be well incorporated within the policies addressed in the sample plans, and this might be a reason why local jurisdictions received relatively low plan quality scores. In addition, this study conducted a cross-sectional analysis due to the limited time and resources for evaluating each plan and difficulties for acquiring longitudinal datasets. Future research may further assess the planning effects (e.g., plan quality scores, participation, capabilities, etc.) over a long range by employing a time-series or panel evaluation methods. Thus, this will demonstrate more precisely how and which specific factors may contribute to the plan quality in response to the policy learning process (Tang et al., 2010).

Fourth, the three variables (plan updated year, number of planners, and the involvement of consultants) that were adopted to represent the planning capacity might be limited in representing the entire planning efforts toward to achieve sustainable stormwater management. Through sending surveys to planning departments or directors in the sample jurisdictions, further research should include other planning factors, such as annual budget for stormwater management, planner's commitment, participation, leadership, and coordination with other departments, to provide more detailed information and resources that may signify the ability of local jurisdictions regarding sustainable stormwater management.

Fifth, this study did not conduct the plan implementation evaluation. There is no notion that high-quality plans will always deliver higher policy implementation. To better understand whether sustainable stormwater management mechanisms are adequately implemented in reality, future research should examine which policies and strategies have been successfully transformed into action and which specific factors contribute to the degree of implementation. For example, studies may assess the degree to which local plans or policies are minimizing the amount of stormwater runoff, reducing stormwater pollutants, and promoting more sustainable stormwater management practices. Additionally, conducting case studies of sites with efficiently installed low impact development practices may help draw a contextual picture of which policies can be useful when they are implemented. Findings from the case studies can also be a good practical evidence to support the quantitative analyses (Brody et al., 2006).

Finally, the evaluation was made only for local comprehensive plans. Even though comprehensive plans suggest the long-range visions of a community and the direction of future developments, actual land developments are more likely to be influenced by detailed plans, programs, manuals, and regulations. Therefore, the evaluations of stormwater management plans or watershed implementation plans, which deal greatly with specific provisions regarding stormwater runoff, will provide additional viewpoints on whether stormwater is appropriately controlled and managed at the site scale. Moreover, to verify the degree to which regional stormwater management efforts are well integrated into local level plans, future studies are recommended to examine whether diverse regional programs associated with stormwater management are properly linked with the local comprehensive plan.

4. EVALUATING LOCAL COMPREHENSIVE PLANS ON THEIR EFFECTIVENESS IN MANAGING STORMWATER SUSTAINBLY

4.1 Synopsis

To understand the effect of local plan quality associated with sustainable stormwater management on surface runoff, an empirical investigation was conducted through evaluating local comprehensive plans within the Chesapeake Bay watershed. The watershed covers about 166,000 km^2 and encompasses seven states in the Mid-Atlantic region, including parts of Delaware, Maryland, New York, Pennsylvania, Virginia, Washington, D.C., and West Virginia. The Chesapeake Bay, which is the largest estuary in the United States, is a critical area for natural resources, but has been significantly polluted due to stormwater runoff caused by rapid urbanization. This study explores the gap in the empirical research by answering two critical questions: (1) To what extent have local jurisdictions integrated the key principles of sustainable stormwater management planning within their comprehensive plans? (2) What are the effects of planning capacities on mean annual runoff and mean annual peak runoff? To address the research questions, the data were analyzed in two phases. First, a developed plan coding protocol was used to assess 42 local comprehensive plans. Second, a multiple regression analysis was used to examine the degree of association of planning factors and other contextual variables with annual mean and peak runoff for 75 sub-basins. The main data of this study are aggregated at the watershed level. Results indicate that the majority of local jurisdictions have relatively weak integration of sustainable stormwater management principles and concepts in to land use plans, with only an average score of 23.58 on a scale of 50. Interestingly, sub-basins that were included in jurisdictions with relatively high plan quality scores tend to generate higher volumes of surface runoff, while sub-basins included in jurisdictions with more planners are likely to produce less runoff. The findings inform local governments, decision-makers, and planners to increase their awareness and understanding about the concept of sustainable stormwater management. This section discusses policy implications and recommendations as to how local planning efforts and capacities may effectively contribute to the mitigation of surface runoff and flash flooding.

4.2 Introduction

Federal and regional legislations have mainly been governing water resources in the U.S. primarily since enactment of the Clean Water Act (CWA) in 1972. Stormwater discharges, however, were not effectively controlled and regulated until the second amendment of the CWA in 1987. By far, the introduction of the National Pollutant Discharge Elimination System (NPDES) permit program had the most impact on giving states authority to control stormwater pollution by regulating point and non-point discharge pollutants. While several initiatives and programs at the national and regional levels have been created to curb development activities that may result in water quality degradation and excessive stormwater runoff, there has been little recognition of stormwater management at the local level. Since the majority of actual developments are regulated by local stormwater regulations, ordinances, and codes, adoption of a stringent local comprehensive plan with adequate sustainable stormwater management policies will enable jurisdictions to manage stormwater more systematically with clear visions, goals, and objectives.

In recent years, a great deal of research has attempted to evaluate plan quality on various scientific aspects, including natural hazards, climate change, sustainability, smart growth, urban sprawl, citizen participation, green infrastructure, ecosystem management, and environmental planning (e.g., Berke, 1994; Berke & Conroy, 2000; Berke, 2002; Berke et al., 1996, 1997; Brody, 2003a; 2003b, 2003c; Brody et al., 2004; Brody et al., 2006; Brody & Highfield, 2005; Burby, 2005; Fu & Tang, 2013; McDonald et al., 2005; Norton, 2005; Talen & Knaap, 2003; Tang, 2008; Tang et al., 2008; Tang & Brody, 2009). However, no research to date has examined local comprehensive plan quality on whether the principles of sustainable stormwater management are incorporated. Moreover, in examining the plan implementation process, several studies are steadily adopting plan quality score as a causal variable (Brody, 2001). While a large number of studies have examined relationships among diverse factors and runoff depth, only few, if any, have thoroughly explored the effects of planning efforts and capacities on surface runoff depth.

In recognition of these gaps, this study first examined the degree to which local jurisdictions within the Chesapeake Bay watershed have successfully integrated the principles of sustainable stormwater management into their local comprehensive plans by developing a specific plan coding protocol. Indicators within the coding protocol allowed us to quantitatively measure the stormwater management effectiveness. The study assessed the effect of local planning capacities on mean annual runoff and mean annual peak runoff in 75 sub-basins within the Chesapeake Bay watershed. Particularly, this study answers two main research questions: *1) To what extent do local jurisdictions integrate sustainable stormwater management principles into their local plans? 2) Do local planning capacities significantly influence mean annual runoff and mean annual peak runoff depth?* Through investigating these questions, this study provides important insights for local planners and decision-makers into mitigating stormwater runoff through the pragmatic local planning process.

4.2.1 The Need for Sustainable Stormwater Management Planning

The occurrence of excessive runoff and flash flooding events is increasing in the United States due to rapid urbanization, climate change, and an aging stormwater infrastructure system. According to the most recent U.S. Census, from 1950 to 2010, urbanized areas expanded by almost 210 percent, and population in urban areas increased by more than 130 percent. Land consumption rate is outpacing the population shift from urban areas to suburban areas (Brody et al., 2006). At the same time, the ability of nature to respond to change has decreased due to rapid urbanization and urban sprawl. Conventional low-density development patterns, which caused environmental degradation, has significantly enlarged the area taken up by impervious surfaces, and thus facilitated landscape fragmentation, habitat displacement, and flood risks (Arnold & Gibbons, 1996; Weber et al., 2006). The influences of land use changes, such as urbanization and deforestation, led to the rising increment of stormwater runoff volume and pollution (Chang & Franczyk, 2008; Lehner et al., 1999). Previous studies (Booth & Jackson, 1997; Brabec, 2009; Paul & Meyer, 2001; Schueler, 1994) have discovered that increased impervious surfaces caused by urbanization generate negative hydrologic consequences, including excessive overflow, lack of infiltration, and insufficient aquifer recharge. Considering the adverse effects of urbanization on watershed characteristics, a substantial body of research has identified that baseflow, peak flow time, and the time of concentration considerably decreased after developments occur, and thus stimulated more flash floods (Arnold & Gibbons, 1996; Brabec, 2009; Cheng et al., 2013; Hirsch et al., 1990; Randolph, 2004; USEPA, 2009).

Due to climate change impacts, the magnitude and duration of precipitation patterns as well as the urban hydrologic cycle have significantly changed (Cheng et al., 2013; Frederick & Major, 1997; IPCC, 2007). However, while more frequent and intensified storm events and floods are occurring recently owing to climate change, the current stormwater systems, which have been constructed mostly based on past climate trends and conventional knowledge, are limited in effectively controlling the excessive runoff during heavy rains.

Downstream water pollution and flooding have been exacerbated because of the early stormwater runoff system design and aging pipeline infrastructure. Specifically, conventional stormwater management approaches have focused on removing stormwater as promptly as possible in order to mitigate impacts from flooding in a particular subdivision (Kaiser & Burby, 1987). Hence, old pipeline drainage systems have increased the volume and velocity of runoff as well as peak flows, which incur greater danger to downstream water bodies in the form of flooding (Kaiser & Burby, 1987). In addition, aging pipeline drainage channels are eyesores – as well as dangerous by causing sinkholes, preventing natural infiltration functions, and degrading the downstream water quality (USEPA, 1988). Maintenance and replacement costs for these pipelines are relatively expensive compared to other on-site management systems such as BMPs and LID techniques (Gaffney, 1964; USEPA, 2010). Unfortunately, the majority of local jurisdictions have historically paid little attention to stormwater management related infrastructure, and funding has been limited by regional and state governments compared to other governmental infrastructure activities such as road and land construction, which are classified as mainstream works (Dollery & Marshall, 1997; Pyzoha, 1994).

In sum, these three problems of rapid urbanization, climate change, and an aging stormwater infrastructure system are significant issues resulting in excessive runoff and will become more problematic as they continue to disturb the hydrological cycle and increase flood damage. Effective control and regulation in the early phases of development can help forestall or resolve these issues. Planning includes diverse planning processes, incorporating the active participation of various stakeholders including a range of different department officials, developers, and residents. The decision-making processes before the actual developments provide local governments an opportunity to more effectively and comprehensively address runoff issues by embracing a wide range of goals toward sustainable stormwater management. In addition, planning is a procedure directed by a plan document that must be a long-range blueprint for a community's future development (Kaiser et al., 1995). Thus, incorporating stormwater management policies while adopting a plan may play a critical role in establishing stormwater management strategies for implementation in the initial stage and help effectively minimize adverse impacts from flooding and overflow. Most importantly, since many factors that cause stormwater runoff—such as rapid urbanization, urban sprawl, and inadequate drainage systems—occur at the local level, the role of local land use decisions is becoming more crucial in managing stormwater (Brody et al., 2004; Kaiser & Burby, 1987).

Local governments are responsible for land use planning; they guide and regulate various urban environments and developments that may directly affect the stormwater system. Therefore, stormwater management should be addressed in the regional or community planning arena, especially within the local comprehensive plan, to proactively and effectively prepare for future stormwater risks and manage stormwater in a manner incorporated into larger concepts such as hazard, environmental, and ecosystem planning.

4.2.2 Plan Quality Evaluation and Sustainable Stormwater Management

A comprehensive plan that plays a significant role in guiding, regulating, and managing current and future land development activities is becoming more crucial at the local level because this role is substantially growing within a community (Berke et al., 2006; Kaiser et al., 1995; Stevens et al., 2014). Through a systematic plan quality evaluation, the overall planning process as well as the strengths and weaknesses with regard to specific issues can be identified, and the findings from the evaluation may provide important evidences in supporting policy-makers' decisions (Berke & Godschalk, 2009; Dalton & Burby, 1994; Talen, 1996). Although plan evaluation may not assure that specific policies will be implemented in practice, several studies have verified that higher-quality plans may better promote certain goals compared to lower-quality plans, including environmental protection, ecosystem management, and hazard mitigation (Berke & Godschalk, 2009; Stevens et al., 2014).

To evaluate the capacity of local jurisdictions on controlling and managing stormwater runoff, it is important to understand how the key principles of sustainable stormwater management can be integrated into local comprehensive plans and policies. By referring to the four major attributes of sustainable development that Berke and Conroy (2000) conceptualized in their study, the concepts of sustainable stormwater management that were established in previous research (Barbosa et al., 2012; Brown, 2005; Brown et al., 2009; Cettner et al., 2014; Cheng et al., 2013; McManus & Brown, 2002; Morison, 2009; Wong, 2001) and various existing federal, state, and local stormwater management guidelines, eight major sustainable stormwater management principles were adopted for this study. The detailed description of these principles is shown in Section 2.2. In addition, through employing previous concepts of plan quality (Brody, 2003c), this study conceptualized definitions of local sustainable stormwater management plan quality based on five key plan components: 1) factual basis; 2) goals and objectives; 3) inter-jurisdictional coordination and capabilities; 4) policies, tools, and strategies; and 5) implementation. Plan quality evaluation through these plan components allowed us the capability of local comprehensive plan and planning efforts to control both stormwater runoff quantity and quality (Brody et al., 2004). Additionally, this study determined the degree to which local jurisdictions have thoroughly integrated the principles of sustainable stormwater management. Detailed conceptual definitions of the five plan components are discussed in Section 3, subsections 3.2.2.1 through 3.2.2.5.

4.2.3 Factors Influencing Surface Runoff

While the vast majority of research have examined the effects of natural environment, built environments, or socio-economic factors on surface runoff or flood damage, there are only a few empirical studies that focused on the planning factors contributing to surface runoff. By recognizing this gap, an explanatory model was developed and tested to identify how planning capacities influence the variation in surface runoff. In addition, the associations among three specific factors (geographical, basin characteristic, and biophysical variables) and runoff were examined. This subsection reviews the literature regarding four sets of variables that significantly influence the amount of runoff.

4.2.3.1 Planning Capacity Variables

Due to the limited number of studies exploring the effect of planning factors on surface runoff, there is not enough empirical evidence to underpin a relationship between planning capacities and runoff generation. However, local planning may play an important role in minimizing and controlling runoff by adopting appropriate land use policies and regulations. Unfortunately, land use planning is not fully applied to stormwater management for a variety of reasons—political, economic, and social—as well as from a lack of awareness. Thus, it is critical to reveal what planning factors stimulate local planners to integrate sustainable stormwater management principles and policies into their comprehensive plans.

Past studies have identified three key sets of planning factors that may promote a local government to adopt policies associated with various hazard mitigation, especially on flooding: internal factors, external factors, and combined internal and external factors (Berke & Beatley, 1992; Dalton & Burby, 1994; Kang, 2009). First, internal factors refer to features that can be controlled by local governments, such as the planning process and institutional capacity. With stringent planning processes devoted to drafting a plan, local jurisdictions may better understand the actual problems through vigorous interactions with various stakeholders at every policy development phase (Brody & Highfield, 2005). In addition, when localities have more resources and expertise, higher-quality plans can be generated, and thus specific policies may have better chances to be implemented (Brody, 2003a; Dalton & Burby, 1994; Kang, 2009). Several previous studies (Burby & May, 1997; Dalton & Burby, 1994; Godschalk et al., 1989) underscored planning staffs or officials play crucial role in mitigating hazards, especially regarding flood damage. In addition, Brody et al. (2006) found that jurisdictions with more planning agency staff had stringent sprawl-mitigation measures in their local comprehensive plans. Tang and Brody (2009) discovered that a larger number of planners contributed to higher-quality local environmental plans. Some other studies further examined the impacts of internal planning factors such as plan quality score, plan updated year, budget, collaborative effort, commitment, participation, and leadership on plan quality or plan outcome (Brody, 2003a; Brody & Highfield, 2005; Kang, 2009; Tang & Brody, 2009). With higher plan quality on stormwater management, which incorporates various non-structural tools (e.g., regulations on land use, taxes, site design, building codes, and public participation and education programs) and structural tools (e.g., LIDs, BMPs, and green infrastructures), local governments tend to have higher commitments to managing and controlling stormwater runoff. Brody and Highfield (2005) identified that plan quality scores of specific environmental and implementation policies had significant correlations with the degree of plan implementation (e.g., wetland development). Nelson and French (2002) discovered that seismic safety elements within local comprehensive plans may have a positive effect in minimizing earthquake damage. Kang (2009) found that plan quality scores of flood mitigation policies were positively associated with insured flood losses, even though the coefficient in this study was statistically insignificant. Furthermore, more recently updated plans are likely to keep apprised of up-to-date information, natural- and built-environmental conditions, and techniques, and thus they may promote local governments to generate better-quality plans and encourage their implementation. Specifically, Tang and Brody (2009) found that recently updated plans had a significant impact in generating higher-quality local environmental plans. Additionally, hiring private consultants may bring more technical and human resources to the table with which to improve plan quality and facilitate implementation. Sufficient financial funds available for stormwater management, and local leaders' or planners' willingness to adopt sustainable stormwater management policies may considerably influence the quality of a plan as well as its implementation. However, due to the limitations in obtaining these data, this study included only four planning factors that may represent local governments' planning efforts and capabilities toward achieving sustainable stormwater management: plan quality score, plan adopted year, number of planners, and participation of consultants while drafting a plan.

On the other hand, external factors, which cannot be directly controlled by local governments but play an important role in policy adoption, are crucial for stimulating jurisdictions to implement stormwater management policies. Several components such as state mandates, unexpected flood events, political and cultural differences, socio-economic attributes of a community, and a number of biophysical factors are included in external factors (Dalton & Burby, 1994; Kang, 2009). By far, state mandates are a powerful top-down regulatory approach that motivates local governments to strive toward high awareness of and motivation to address regional problems (Tang et al., 2010). In addition, the existence of a state mandate contributes to development of high-quality plans in local jurisdictions (Berke et al., 1999; Berke & French, 1994; Burby & May, 1997). Kaiser and Burby (1987) found that local governments where there were state mandatory local actions or state model stormwater management ordinances tended to adopt more stormwater management regulations. However, present efforts on legislative mandates with regard to stormwater management are comparatively weak in the U.S. (Roy et al., 2008). Insufficient federal- and state-level legal obligations to control stormwater runoff may cause inconsistent jurisdiction management policies (Roy et al., 2008).

In addition, land development impact, which is a result of the combination of internal and external factors, may significantly influence stormwater runoff. Internally, development pressure can be controlled by adopting various types of structural and non-structural stormwater management policies. Externally, however, rapid urbanization and growth of a community may not be readily regulated by local planning efforts.

Certainly there are limitations to verifying the degree to which local comprehensive plans or planning factors affect, in practice, the implementation of plan parameters. Although the aim of this study is not to examine plan implementation mechanisms by evaluating the conformity of outcomes, local jurisdictions with high-quality plans and commitment to local planning will likely have stronger awareness and ability to mitigate stormwater runoff.

Local comprehensive plans may provide a spatial guidance or blueprint for future development patterns since they incorporate broad goals and specific policies/strategies as well as thorough decision-making processes that engage various stakeholders (Brody & Highfield, 2005). Thus, evaluating the quality of local comprehensive plans can be a suitable alternative approach to finding out whether outcomes conform to the initial intent of a plan (Brody & Highfield, 2005). Based on this guidance, this study tested the following hypotheses:

Hypothesis 1: *Sub-basins with higher plan quality in terms of sustainable stormwater management will generate less surface runoff.*

Hypothesis 2: *Sub-basins, which are included in jurisdictions that have recent plan adoption, are less likely to generate excessive surface runoff.*

Hypothesis 3: *Sub-basins, which are included in jurisdictions with more planners while drafting a local comprehensive plan, will generate less surface runoff.*

Hypothesis 4: *Sub-basins, which are included in jurisdictions that engage private consultants while drafting a local comprehensive plan, will generate less surface runoff.*

4.2.3.2 Geographical Variables

Urbanization often affects overland water flow by increasing impermeable surfaces. In urban centers, impervious surfaces take more than 80 percent of the surface area, while suburban areas have an average of 20 to 50 percent impervious surfaces (Braden & Johnston, 2004). Hydrologic attributes change greatly once imperviousness exceeds 25 percent of a watershed (Schueler, 1994). For instance, one study showed that runoff doubled when impervious surfaces increased by only 10 to 20 percent (Arnold & Gibbons, 1996). Another found the increase of impervious surfaces had a positive and strong correlation with the change of stream flow (Brody et al., 2007). The Natural Resources Conservation Service (NRCS, 1998) compared the runoff percentage of natural ground cover and urbanized areas and found that infiltration rate was reduced by 35 percent and runoff increased by approximately 45 percent in urban areas. Moreover, studies from Hosseinzadeh (2005) and Sala (2003) show that stormwater runoff and flash floods in urbanized areas significantly increased as a result of increased presence of impervious surfaces.

In addition, the impacts of land cover changes are the main cause of hydro-modification in a watershed (Gearheart, 2007). Post-development's peak flow time, the time of concentration, and baseflow can be decreased compared to the pre-development flow regime (Brabec, 2009; Cheng et al., 2013; Randolph, 2004; USEPA, 2009). The changes are mainly due to decreased infiltration and increased evapotranspiration functions. The increase of impervious surfaces and drainage pipelines expand the peak discharge from a certain storm (Arnold & Gibbons, 1996; Booth & Jackson, 1997; Randolph, 2004; Schueler, 1994). In particular, surface runoff is increased by the reduced infiltration of water, and the hydrograph lag time is decreased by the increased rate of runoff accumulation (Randolph, 2004). In sum, a substantial body of research has proved that the increase of impervious surfaces triggered from rapid urbanization significantly increases runoff volume, degrades water quality, and facilitates flood risks.

In contrast, the capacity of filtration and detention can be maintained by conserving natural land covers. In particular, natural land covers stabilize and protect soils from wind and water erosion and thus mitigate nutrient runoff (Heinze, 2011). They also influence hydrology by 1) intercepting precipitation with tree foliage, 2) reducing the peak runoff rates into water bodies, and 3) reducing soil erosion and pollutant wash-off (Akpinar, 2013; Tyrvainen et al., 2005). Yang et al. (2013) investigated the effects of urban green space on stormwater runoff by using the lab experimental data of soil columns in Tianjin, China, and found that urban green spaces can be an effective way to minimize the volume of stormwater runoff. In addition, by examining the Federal Emergency Management Agency's (FEMA's) Community Rating Systems (CRS), Brody and Highfield (2013) discovered that a one-point increase of open space protection activity may significantly decrease the insured flood damage.

Wetlands, where saturated with water, link the land and water (USEPA, 2004). From rapid urbanization, however, wetlands have continually disappeared and altered to become agricultural lands or developed lands. Approximately 215 million acres of wetlands have been converted to other land uses in the US (Randolph, 2004). However, the hydrological functions of wetlands, which include sediment stabilization and groundwater discharge/recharge, are important to effectively manage stormwater runoff. A number of previous studies have shown that wetlands reduce the volume of streamflow as well as peak flow (Highfield, 2008). Demissi et al. (1991) assessed the relationships between the percentage of wetlands within a watershed and peak flow; they identified that peak flow reduces as wetland areas increase. Novitski (1985) also found that higher percentages of wetlands may increase runoffs in specific seasons and reduce base streamflows. Moreover, wetland alternation has been statistically proven to increase flood damage (Brody et al., 2008; Brody et al., 2011; Brody & Gunn, 2013). These findings prompted the following hypotheses for this study:

Hypothesis 5: *Sub-basins with a higher percentage of impervious surfaces will generate more surface runoff.*

Hypothesis 6: *Sub-basins with a lower percentage of natural land covers will generate more surface runoff.*

Hypothesis 7: *Sub-basins with a lower percentage of wetlands will generate more surface runoff.*

4.2.3.3 Basin Characteristics Variables

Information regarding basin (or watershed) topography can be obtained from the average surface slope, which provides information regarding the distribution of a basin's slope (Berger & Entekhabi, 2001). The velocity of water can be significantly influenced by the land slope, and thus, overland and channel flow may occur depending on the gradient (Randolph, 2004). Specifically, the time of concentration is drastically influenced by average slope. Stuckey (2006) identified that as a slope steepens, the velocity and the amount of stream peaks increase and annual flows rise due to increased amounts of rainfall concentration. Dunn and Leopold (1978) also discovered that urban runoff increases as slopes get steeper, and thus more erosion and sediment transport to surface waters. Studies such as those by Brody and Highfield (2013) and Highfield and Brody (2013) used mean slopes as a control variable and found that a 1 percent increase of mean slope may significantly increase insured flood losses, holding all the other variables constant.

Watersheds are usually defined by elevation, and there are generally two types of watershed shape: circular watershed and elongated watershed. Typically, an elongated watershed generates a lower outlet flow than a circular (fan) shape of watershed since the time of concentration is higher. Watersheds that have longer and narrower streams, possess relatively sufficient time while upstream runoff flows into downstream. Thus, peak flow rates of elongated watersheds are often lower than in circular watersheds (Matthai, 1990). These variations led us to the following hypotheses:

Hypothesis 8: *Sub-basins with steeper average slopes will generate more surface runoff.*

Hypothesis 9: *More elongated sub-basins will generate less surface runoff.*

4.2.3.4 Biophysical Variables

Precipitation is well known to be the most significant variable that influences runoff discharge volume and results in flooding. Runoff occurs when precipitation overwhelms a watershed's absorbing capacity or the ability of urban drainage systems (Mount, 1995). The volume of runoff is significantly affected by the magnitude and duration of precipitation (Cheng et al., 2013; DEH, 2002; IPCC, 2007). Generally, longer rainfall results in a greater volume of water, which can lead to higher magnitude of runoff (Mount, 1995; Pitt & Clark, 2008). Wardrop et al. (2005) identified average monthly precipitation as one of the most significant contributors of hydrologic response in the Mid-Atlantic region. Some studies used proxy variables such as flood damage to reveal the relationship between precipitation and flooding, and found that precipitation has positive and significant effects on flood damage (Brody et al., 2007; 2011; 2013). Due to climate change impacts, more runoff is anticipated to be generated in the US in coming years (Brabec, 2009; Cheng et al., 2013).

Since precipitation datasets are mostly recorded at point locations (stations), the amount of rainfall for the whole watershed should be estimated by spatial interpolation

(Running & Thornton, 1996). The precipitation records for this study used datasets provided by Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group, which modeled the long-term average precipitation pattern by employing climatologically-aided interpolation (CAI).

Storm surge events are explicitly related to overland flow and they may produce sudden and catastrophic damage (Brody et al., 2011). Poorly designed drainage systems or highly urbanized areas are apt to be damaged significantly by surge events, which cause excessive urban stormwater runoff. Brody and his colleagues (Brody et al., 2011; Brody & Highfield, 2013; Highfield & Brody, 2013) used surge events as a variable to examine the effects on insured flood losses, and found that areas with more surge events had more flood damage.

An important factor in addressing stormwater runoff volume is the percentage pertaining to the 100-year floodplain, where there is 1 percent chance of flooding each year. Floodplain has been used as a key marker of flood risk (Brody et al., 2011). Specifically, "floodplains occupy those areas adjacent to stream channels that become inundated with stormwater during large rainfall/runoff events" (Shaver et al., 2007, p. 206). Protecting floodplains is crucial to reducing flood damage and stormwater runoff as well as to maintaining natural storage capacity (Brody & Highfield, 2013). If development happens within the floodplain, there will be higher chances of flooding and runoff issues. Several studies (Brody et al., 2011; Brody & Gunn, 2013; Brody & Highfield, 2013; Highfield & Brody, 2013; Kang, 2009) have used floodplain areas as a variable to examine the impacts on insured flood losses and found that the increase in percentage of floodplain area correlates to increased flood-related damage.

Natural drainage density is a ratio expressed by dividing stream length by total area of a basin. It has often been used as a key indicator to identify the hydrologic responses of a landscape (Berger & Entekhabi, 2001). A watershed that has been highly cut apart by streams generally responds promptly to rainfall events (Horton, 1932). Drainage density is related to stream frequency of a watershed, and the relationship with the rate of infiltration is known to be inverse (Bell, 2004).

Soil permeability or compaction can be a significant factor that affects the quantity of stormwater runoff. Depending on the infiltration capacity of the soils, amounts of overland flow and infiltration into groundwater will be different. Areas containing higher porosity soils are less likely to be damaged by floods or excessive runoffs (Brody, 2013; Chang & Franczyk, 2008). Cahill (2012) demonstrated that soil compaction caused by land development produces more runoff than the pre-development soil conditions. As a proxy to represent more detailed levels of soil characteristics, saturated hydraulic conductivity (K_{sat}) was used in this study. Saturated hydraulic conductivity is often used in soil interpretation, which refers to "the ease with which pores in a saturated soil transmit water" (SSSNNE, 2009, p. 3). It has also been employed as an important parameter for understanding the water movement of soils (Blanco-Canqui et al., 2002). The estimates are shown in micrometers per second and they can be classified into six groups based on the standard K_{sat} class limits (NRCS, 2008): 1) very low (0.00-0.01); 2) low (0.02-0.1); 3) moderately low (0.2-1.0); 4) moderately high (1.1-10); 5) high (11-100); 6) very high (101-705).

Several previous studies have used soil permeability as a variable to examine the effects on flood damage (Brody et al., 2011; Brody & Highfield, 2013; Brody et al., 2013; Highfield & Brody, 2013) and streamflow (Yang & Li, 2011). In particular, Brody and his colleagues (Brody & Highfield, 2013; Brody et al., 2013; Highfield & Brody, 2013) identified that soil permeability has a statistically significant impact on decreasing observed flood damage, holding constant all other variables. Yang and Li (2011) concentrated on soil permeability to examine the streamflow of The Woodlands, Texas, and discovered that the streamflow increases due to the increased development density and indiscriminate developments that occurred upon permeable soil areas. Barbosa and Hvitved-Jacobsen (2001) emphasized the importance of soil types and thicknesses since they may increase runoff volumes. In addition, land infiltration capacity can be increased by soil permeability, but there is also a high chance that groundwater gets contaminated. The following hypotheses resulted from this line of investigation:

Hypothesis 10: *Sub-basins with a larger amount of precipitation will generate more surface runoff.*

Hypothesis 11: *Sub-basins that are flashier will generate more surface runoff.*

Hypothesis 12: *Sub-basins with higher natural drainage density will generate more surface runoff.*

Hypothesis 13: *Sub-basins with a higher percentage of floodplain areas will generate more surface runoff.*

Hypothesis 14: *Sub-basins with higher saturated hydraulic conductivity will generate less surface runoff.*

4.3 Research Methods

4.3.1 Conceptual Model

To further conceptually understand and explain the effects of planning capacities and the other three specific factors discussed earlier (geographical, basin characteristics, and biophysical variables) on runoff depth, a conceptual model was developed (Figure 4.1). More specifically, within the planning capacity variables, plan quality scores have been derived by evaluating whether local jurisdictions in the sample sufficiently integrate the principles of sustainable stormwater management into local comprehensive plans. Plan coding protocol has been developed through thorough review of past literature associated with plan quality evaluation and stormwater management. Other planning capacity variables include plan adopted year, number of planners, and existence of private consultants while drafting a plan. Geographical variables contain the percentage of impervious surfaces, natural land covers, and wetlands. Basin characteristics variables embrace average slope and basin shape. Lastly, biophysical variables include average precipitation, the number of days of flash flood events, natural drainage density, the percentage of 100-year floodplain, and soil permeability.

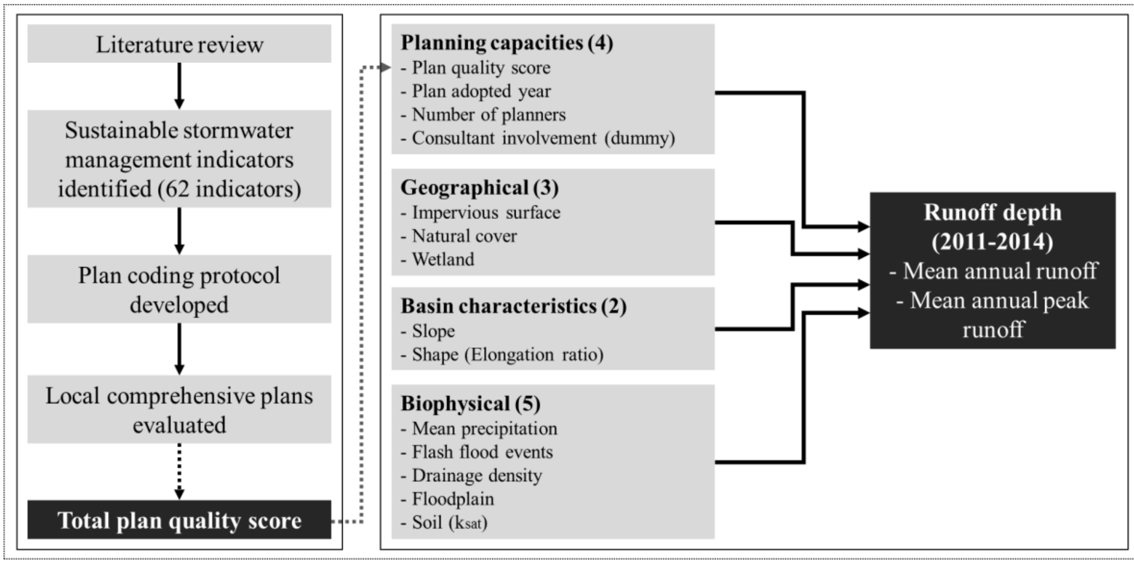

Figure 4.1. Conceptual Model

4.3.2 Study Area and Sample Selection

The target population of this study is sub-basins within the Chesapeake Bay watershed. The Chesapeake Bay is the largest and most biologically diverse estuary in North America located in the Mid-Atlantic region (Chesapeake Bay Program, 2000). The watershed covers approximately 166,000 km^2 and a total of 203 counties and independent cities lie within or adjoining the bay watershed (see Figure 4.2). The study area has historically been polluted by human developments and impervious surfaces accompanied by rapid population growth. The population in the watershed has doubled between 1950 and 2000 (from 8 to 16 million), which resulted in an impaired bay ecosystem, including habitat loss and water quantity/quality degradation (Phillips, 2006). Most importantly, approximately 15 percent of the total nitrogen entering the bay originates from urban and suburban polluted runoff, which has been recently recognized as the most growing threat to bay water quality (USEPA, 2008).

The sample for this research was chosen based on the following steps. First, local jurisdictions that intersect with the Chesapeake Bay watershed boundary by more than 50 percent were selected to avoid the sample jurisdictions that may not directly influence the entire watershed ecosystem. Second, the sample was limited to jurisdictions with populations greater than 10,000 to prevent skew toward small jurisdictions, where areas often lack the resources to initiate a sufficient planning effort (Berke & Conroy, 2000). Third, jurisdictions that adopted comprehensive plans between 2000 and 2010 were selected to determine the effect of planning factors on mean and peak annual runoff depths from 2011 to 2014. Finally, sub-basins that overlap with the boundary of a specific jurisdiction by more than 80 percent were chosen for the final sample, in order to represent the planning factors where the unit of analysis is at the county level. Through the above selection process, a total of 42 local jurisdictions and 75 sub-basins were contained in the sample.

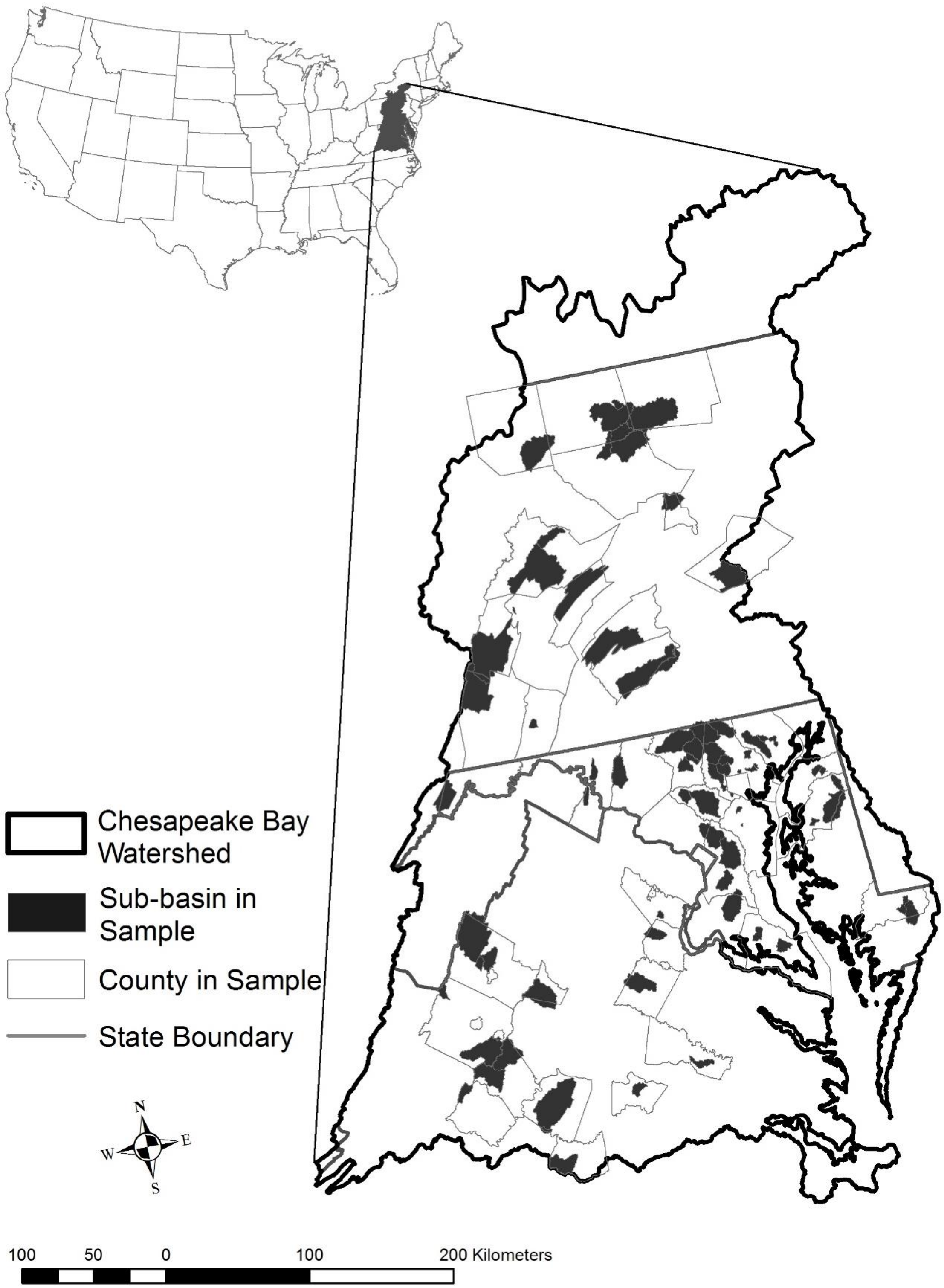

Figure 4.2. Selected Sub-basins in the Chesapeake Bay Watershed

4.3.3 Unit of Analysis

The unit of analysis for this study is at the sub-basin level. The sample sub-basins have been delineated based on stream gauge data from the USGS by following three sampling processes. First, a gauge that has its outlet located within a reservoir or dam was excluded from the sample since the data can be impacted by storage capacity. Second, only gauges that have streamflow records between 2011 and 2014 were chosen for the final study, in order to examine the implementation effects of local plans that were adopted from 2000 to 2010. Third, for data efficiency and accuracy only gauges that have at least 90 percent of streamflow records per year were selected (Highfield, 2012).

By using StreamStats, a Web-based GIS application that was developed by the USGS and ESRI for water resources planning and management, a distinct sub-basin boundary from each gauge station was delineated. In particular, digital elevation models (DEM), flow accumulation, and flow direction were calculated within the program to delineate unique sub-basins.

4.3.4 Concept Measurement

4.3.4.1 Dependent Variables

Given the fact that the magnitude and frequency of flooding in streams were significantly impacted by the volume of surface runoff (Brody et al., 2007), mean annual runoff and mean annual peak runoff of 75 sub-basins from 2011 to 2014 were used for the dependent variables. Because the USGS gauge stations provided the daily mean and peak discharge rates for each sub-basin with the unit of cubic meter per second (m^3/s), this study converted the flows into total annual runoff depth (in millimeters). Specifically, the converting method that the USGS applied for its estimation was employed. First, 86,400 seconds per day was multiplied to convert the value into a total annual flow volume (cubic meter). Second, runoff volume expressed in depth was computed by dividing the total annual flow volume by the contributing drainage area, which was measured by ArcGIS. Third, meter measurement has been converted into the millimeter measurement by multiplying 1,000. This study did not use the runoff ratio (runoff / precipitation) as the dependent variable because the samples' runoffs were not significantly different from each other during the study period. Precipitation was instead included as one of the control variables. Table 4.1 summarizes the two dependent variables. While the values of mean annual runoff were normally distributed, mean annual peak runoff was skewed. To better approximate a normal distribution, mean annual peak runoff was log-transformed in this study. The distributions of two dependent variables are graphically presented in Figures 4.3 and 4.4. Mean annual runoff and mean annual peak runoff data for each gauge are presented in Appendix C.

Table 4.1. Concept Measurement

Variable	Description	Data source	Mean	S.D	Range
Dependent variables					
Mean annual runoff depth	Mean annual streamflow at each USGS gauge station divided by basin area (mm)	USGS (2011-2014)	1.34	0.36	0.60-2.10
Mean annual peak runoff depth (log)	Mean annual peak streamflow at each USGS gauge station divided by basin area (mm)	USGS (2011-2014)	7.79	1.08	4.24-9.91
Planning capacity variables					
Plan quality score	Five plan components' score (point)	Plan coding protocol (2000-2010)	23.58	5.81	7.56-33.14
Plan year	Plan adopted year minus 2010	Each jurisdiction's plan (2000-2010)	-3.07	3.09	-10-0
Planning staff	# of planning staff during creating plan	Each jurisdiction's plan (2000-2010)	5.75	3.93	1-19
Consultant	Existence of consultants involved during adopting/creating plan (1=yes, 0=no)	Each jurisdiction's plan (2000-2010)	0.47	0.50	0-1
Geographical variables					
Impervious surface	% impervious land cover; NLCD Class 22, 23, 24	USGS (2011)	21.59	25.83	0.9-95.21
Natural cover	% natural land cover; NLCD Class 41, 42, 43, 52, 71, 81	USGS (2011)	60.84	27.61	4.02-98.28
Wetland	% wetland land cover; NLCD Class 90, 95	USGS (2011)	3.54	7.25	0-51.49
Basin characteristics variables					
Slope	Average percent slope of sub-basin	USEPA - NHDPlusV2 (2012)	10.09	7.36	0.76-32.47
Shape	Circumference of a circle with the same area; *Elongation ratio*	ArcGIS	0.58	0.13	0.33-0.98
Biophysical variables					
Precipitation	Average monthly rainfall (mm)	PRISM (2011-2014)	1,143.97	83.29	942.21-1,357.79
Flash flood events	# of days exceeding the base discharge	USGS (2011-2014)	12.69	5.78	0-34
Floodplain	% overlapping a FEMA-defined 100-year floodplain (DFIRM)	FEMA Map Service Center (2014)	5.50	3.46	0-17.27
Natural drainage density	Total length of basin streams divided by basin area	USDA (2003)	1.28	0.32	0.35-2.02
Soil	Saturated hydraulic conductivity (Ksat) by SSURGO	USDA (2003)	3.07	1.89	0.87-10.67
Observation is 75 for all variables					

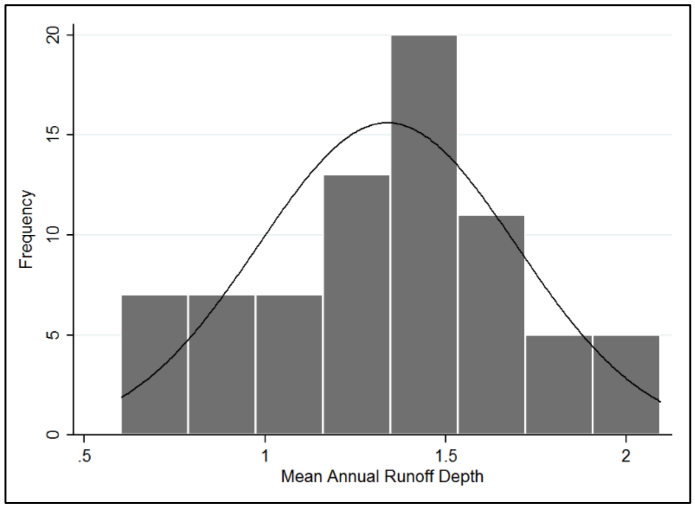

Figure 4.3. Histogram of Mean Annual Runoff Depth

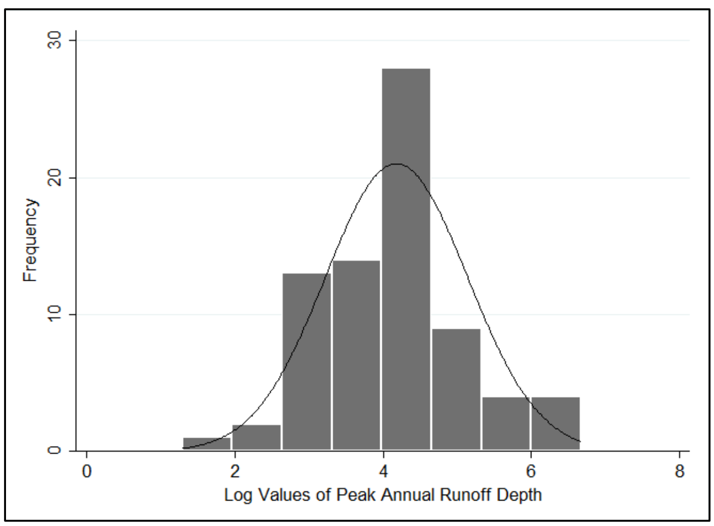

Figure 4.4. Histogram of Log-transformed Peak Annual Runoff Depth

4.3.4.2 Independent Variables

4.3.4.2.1 Planning Capacity Variables

Four planning factors have been used in this study to represent planning capacities of local governments toward achieving sustainable stormwater management:

plan quality score, plan adopted year, number of planners, and participation of consultants while drafting a plan.

Plan quality scores of each local jurisdiction were measured following the approach that was often employed in past plan evaluation studies (Berke et al., 1996; Brody, 2003c; 2008; Tang et al., 2010). The five plan components protocol that was conceptualized in a previous section (4.2.3) was applied to evaluate whether the 62 indicators associated with sustainable stormwater management principles have been well addressed in local comprehensive plans.

Specifically, total plan quality scores for each jurisdiction were calculated in four steps. First, all indicator scores within a plan component were summed. Each indicator was coded on a 0-2 ordinal scale except the indicators within the "goals and objectives" component, which were measured on a 0-1 ordinal scale. If an indicator was not mentioned or identified within a plan, it was scored 0. When an indicator was identified but not in detail, a score of 1 was given. If an indicator was completely illustrated and identified within a plan, 2 was given. However, the "factual basis" component and the "policies, tools, and strategies" component had slightly different scoring systems. For the "factual basis" component, indicators were comprised by a map, text, or both. Thus, scores for indicators in this case were first added to the score of the illustrated approaches and divided by the total number of approaches. For instance, if an indicator scored 1 for map and 1 for text, it received a total score of 1 ((1+1)/2). For the "policies, tools, and strategies" component an indicator scored 0 if it was not mentioned within a plan. If an indicator was described by using the moderate words "consider," “encourage,” “prefer,” “may,” “should,” and “suggest” within a plan, it received a score of 1. In addition, even though a policy was mentioned within a plan but was not described in terms of “what,” “when,” “where,” and “how,” it scored 1. Finally, if an indicator used strong compulsory and firm commitment words, such as “must,” “require,” “shall,” and “will,” with a clear description, it scored 2 (Brody, 2008). Second, the total indicator scores within a component were divided by the total available scores that a component can have in order to standardize the each plan component. Third, each component score was multiplied by ten to make a scale from 0 to 10. Finally, all five component scores were summed up, which brought the total plan quality score scales from 0 to 50 (Brody, 2008). Equations (1) and (2) more clearly and concisely illustrate the plan quality measurement processes (Brody, 2003c; 2008).

$$PC_j = \frac{10}{2m_j}\sum_{i=1}^{m_j} I_i \;.....(1)$$

where PC_j refers to the quality of the j^{th} plan component; m_j refers to the total number of indicators within the j^{th} plan component (scale: 0-10); I_i refers to the i^{th} indicator’s scores (scale: 0-2)

$$TPQ = \sum_{j=1}^{5} PC_j \;.....(2)$$

where TPQ refers to the entire plan quality scores (scale: 0-50)

Plan adopted year data were computed by subtracting the year that a plan was adopted from the year 2010. Data on the number of planners and the existence of consultants while drafting a plan were obtained from each local jurisdiction's comprehensive plan. Individual contacts have been made with local planning department directors where sufficient information was not provided within a plan.

4.3.4.2.2 Geographical Variables

Three land cover datasets are included in this variable: developed area, natural cover area, and wetland area. The 2011 land use/land cover dataset has been obtained from the USGS National Land Cover Database (NLCD) at 30m resolution. In particular, developed areas were represented by grouping three land use/land cover classes (LULC Class: 22-24): low-intensity, medium-intensity, and high-intensity developed areas. These intensities were classified based on the percentage of impervious cover, and each comprises 21-49 percent, 50-79 percent, and 80-100 percent of impervious surfaces, respectively. Land uses for low- and medium-intensity developed areas are typically single-family housing, whereas high-intensity developed areas generally contain apartment complexes and commercial/industrial facilities (Homer et al., 2004). The mixture of six LULC classes (deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, and pasture/hay; LULC Class: 41-43, 52, 71, 81) represented natural cover areas (Highfield, 2012). Wetland areas were represented by two LULC classes (woody wetland and emergent herbaceous wetland; LULC Class: 90, 95). The percentages of LULC distribution were calculated by ArcGIS with the Geospatial Modelling Environment (GME) (Beyer, 2010) extension.

4.3.4.2.3 Basin Characteristics Variables

Both mean slope and basin shape were measured by using ArcGIS. Specifically, mean slope was created based on the 30m resolution DEMs obtained from National Hydrography Dataset (NHD) Plus Version 2. Among several basin shape measurements, such as circularity ratio, length to width ratio, and elongation ratio, this study employed the elongation ratio approach, which is frequently used in recent hydrological research. The value of elongation ratio was attained through calculating equation (3).

$$\textit{Elongation Ratio} = \frac{\sqrt{4 \times \frac{A}{\pi}}}{L} \;\; .....(3)$$

where A refers to the basin area; L refers to the basin length from the gauge station to the farthest point within a basin boundary

4.3.4.2.4 Biophysical Variables

Five biophysical factors that may directly/indirectly influence the quantity of stormwater runoff are included in this variable: average monthly precipitation, number of days of flash flood events, natural drainage density, percentage of 100-year floodplain, and soil characteristics.

Average monthly precipitation data were acquired from the PRISM Climate Group for the period from 2011 to 2014. PRISM Climate Group produced a continuous record of surface precipitation by using the CAI approach. Each basin's monthly average precipitation was summed over the water year (October 1 to September 30) and each basin's average precipitation for the study period was measured using ArcGIS with the GME extension to calculate average weighted mean of raster data.

Each gauge station's flash flood events data were collected from the USGS Water Resources Data Report. Specifically, the number of days that peak discharges were greater than base discharge in each water year was counted from 2011 to 2014. Natural drainage density was measured using ArcGIS with the national hydrography dataset obtained from the USDA's GeoSpatial Data Gateway. The ratio of total stream length to basin area was calculated. The digital flood insurance rate map (DFIRM) was obtained from the FEMA Map Service Center to calculate the percentage overlapping a FEMA-defined 100-year floodplain with the basin area. To obtain the saturated hydraulic conductivity (K_{sat}) value, which is often used in soil interpretation, the Soil Survey Geographic Database (SSURGO) was obtained from the USDA's Web Soil Survey and run using the Soil Data Viewer 6.1. Average K_{sat} value of each sub-basin was then created by using ArcGIS GEM extension to weight the value according to the proportional areas.

4.3.5 Data Analysis

The data analysis of this study is composed in two phases. In Phase 1, descriptive statistics examined whether 42 local jurisdictions in the sample have fully incorporated the concepts of sustainable stormwater management in their local plans. The plan quality scores that were obtained from the above process have been included as one of the key planning capacity variables in the next phase.

Phase 2 focused on identifying specific factors that may affect mean annual runoff and mean annual peak runoff through multivariate regression analyses. An ordinary least squares (OLS) technique was used to test how the independent variables (planning capacity, geographical, basin characteristics, and biophysical factors) explain the variance of dependent variables. Due to the relatively small sample size (n=75) compared to the number of independent variables, variables were analyzed by four block groups. Thus, five models have been analyzed in this analysis. Specifically, Model 1 (baseline model) included only the block group of planning capacity variables. Geographical, basin characteristics, and biophysical variables were then added one by one to create the next models: the block groups of planning capacities and geographical variables were included in Model 2; the block groups of planning capacities and basin characteristics variables were comprised in Model 3; the block group of planning capacities and biophysical variables were added in Model 4. Statistically significant variables in each of four models were then chosen for the final fully specified model (Model 5). By following equation (4), multiple regression analyses were conducted.

$$\boldsymbol{MAR\ \&\ MAPR = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon\ .....(4)}$$

where, MAR refers to mean annual runoff; MAPR refers to mean annual peak runoff; α *refers to regression intercept;* β_x *refers to partial regression coefficients;* X_1 *refers to* *planning capacity factors;* X_2 *refers to geographical factors;* X_3 *refers to basin characteristics factors;* X_4 *refers to biophysical factors*

To ensure that OLS regression assumptions were not violated and to check whether the OLS would yield best, linear, and unbiased estimates, this study tested model specification, outliers, multicollinearity, heteroskedasticity, and spatial autocorrelation. First, the Ramsey Regression Equation Specification Error Test (RESET) revealed that the regression models with the dependent variable of mean annual runoff and mean annual peak runoff were reliable (p=0.121 and p=0.221, respectively), meaning that no linear combinations of the independent variables explain the dependent variable (Wooldridge, 2009). Second, multicollinearity was checked by looking at the Variance Inflation Factor (VIF) and values were less than 10 for all independent variables in both regression models. Third, the kurtosis and skewness values of the mean annual runoff (dependent variable) were 2.5 and -0.2 and the values of the mean annual peak runoff were 4.6 and 0.3, which were less than 5 and 0.8, respectively. Skewness/kurtosis tests for normality were also statistically insignificant at the 0.05 level for both models (p=0.502 and 0.751 for the skewness test; p=0.459 and 0.161 for the kurtosis test). This shows that the regression models does not have any normality issue. Fourth, a Cook and Weisberg test for heteroskedasticity was statistically insignificant at the 0.05 level (p=0.220 and 0.308, respectively), revealing that the residuals of both models tend to have constant variances. Finally, a Moran's I test for spatial autocorrelation was statistically insignificant at the 0.05 level for both models

(p=0.086 and 0.396, respectively) with the values of 0.032 and -0.005. This ensures that the dependent variable's neighboring values are dissimilar and the regression models may not suffer from spatial autocorrelation (Highfield, 2012).

4.3.6 Validity and Reliability Threats

4.3.6.1 Validity Threats

Although this study attempted to construct a thorough research design, validity threats remained during the analysis and they should not be ignored. Validity concerns truth, meaning that it determines whether the instrument measures draw what its user intended to measure (Krippendorf, 2013). In research, validity is the process of proving that the claims from the research are coming from the facts (Krippendorf, 2013). Thus, it deals with the accuracy of the measurement. In qualitative studies, "validity refers to the degree to which a finding is judged to have been interpreted in a correct way" (Maxwell, 1996, p. 4). Cook and Campbell (1979) categorized validity into four types: statistical conclusion validity, internal validity, construct validity, and external validity. This study addressed these four types of validity threats to produce stringent results and inferences.

Statistical conclusion validity is the degree of confidence in the statistical verification. That is, it determines whether statistics processes have been appropriately used to infer the correlation between independent and dependent variables (Shadish et al., 2002). Specifically, two types of errors (Type I: incorrectly determining a correlation exists when one does not; Type II: incorrectly determining no correlation is present when one exists) within the regression analysis are the main concerns of statistical conclusion validity. Among the common threats to statistical conclusion validity, low statistical power can be problematic in this study. Low power occurs when a study has a relatively small sample size. Since this study used only 75 sub-basins as its sample, statistical conclusion validity may be threatened. Specifically, a single data or small number of outliers may bias the regression results. Therefore, it is important to examine the significance of each individual variable and identify factors that may affect the regression analysis (Brody, 2001). Considering the above fact, this study employed the regression blocking technique while conducting multiple regression analyses, in order to alleviate the impact of each variable on the validity of statistical conclusion. Independent variables were grouped into four blocks and only the statistically significant variables on each model were chosen for the fully specified model. These approaches were previously applied by Brody (2001), Tang and Brody (2009), Tang et al. (2010), and Kang (2009) in their respective plan quality evaluations, where sample size was relatively small compared to the number of independent variables.

Internal validity is used when determining whether an experiment was well done insofar as avoiding confounding. Confounding here means that more than one independent variable may affect the dependent variable simultaneously (Indiana University Dictionary, 2013). Thus, internal validity will be high when the confounding in a research is low. Because there are a number of factors that may affect the plan quality as well as stormwater runoff, this study's internal validity could be threatened (Brody, 2001). The dependent variables, mean annual runoff and mean annual peak runoff, can be influenced by diverse natural and built environments, planning efforts, socio-economic, political, and institutional factors. For example, the volume of stormwater runoff could be influenced by political power, politicians' will, unexpected secondary effects from diverse small and large hazards, and various conditions of natural environments. However, all factors cannot be considered in the regression model and, even if they are included in a model, there can be other attributes that may explain the regression analysis outcomes. To ease the extent of internal validity threat and minimize the possibility of spurious relationships in this study, all essential independent variables that may influence the dependent variables were included. In addition, the biggest threat of internal validity in this study may be associated with the study period. In order to reflect the causal relationships between independent variables and the dependent variables, local comprehensive plans should be adopted or amended before the time of collecting mean annual runoff and mean annual peak runoff (dependent variables), which was from 2011 to 2014. Given this fact, local plans in the sample were only selected for those that had been developed between 2000 and 2010 to minimize history threats. Moreover, since some USGS gauge stations did not record all streamflow data, internal validity can be threatened with regard to instrumental issues. Thus, this study delineated only the sub-basins where the stream gauge stations had more than 90 percent of streamflow records per year (Highfield, 2012). In addition, only local jurisdictions and sub-basins within the Chesapeake Bay watershed were addressed in this study to reduce selection threats. Therefore, the samples are likely to have a similar type of rainfall distribution and natural environment, as well as similar flood experiences since they are clustered around each other.

Construct validity refers to assessing the extent to which an instrument measures the construct as it was purposed to measure (Pedhazur & Schmelkin, 1991). In addition, it investigates the degree to which inferences from variables can explain theoretical constructs (Pedhazur & Schmelkin, 1991). Through a thorough literature review, the theoretical relationships between specific factors and runoff/flooding were explained and incorporated in the research model. The other threat to construct validity on the dependent variables is potential limited accuracy of data. Although the streamflow data from the USGS gauge stations provided actual real-time data, they may not perfectly represent that runoff is generated from urban developments or human impacts. Also, they may not completely indicate that the volume of mean annual runoff and mean annual peak runoff is impacted by the entire sub-basin area because the flow data were collected from a single gauge station. To improve the construct validity of plan quality, this study cautiously developed the uniform evaluation criteria with indicators equally weighted based on the various institutions' stormwater guidelines and previous plan coding protocol (Berke & Godschalk, 2009). In addition, this study adopted the measurement procedure that was repeatedly used in previous plan evaluation studies (Norton, 2008; Berke et al., 1996; Brody, 2003c; 2008; Tang et al., 2010).

External validity mainly refers to what extent a study's results can be generalized to other areas at other times. External validity is a potential validity threat in this research design mainly due to the characteristics of the study area. Different natural, physical, socio-economic, and governmental settings may impact differently on the hydrologic attributes. For instance, areas that have comparatively long histories, with strong support from the state, of developing stormwater management ordinances and regulations may generate less runoff. Also, jurisdictions located in coastal areas or with different trends on precipitation as well as weather conditions may react differently to stormwater management. Thus, various factors should be considered when applying the results to other regions. The findings of this research can be best generalized to areas with similar weather conditions, have similar precipitation patterns, are located in inland areas, and have stringent state will in supporting stormwater management activities. However, the methods adopted in this study can be applied to other areas. Furthermore, a comprehensive plan shows the vision of a community. Since we may not guarantee that all the policies and regulations within a local plan will be implemented in practice, higher plan quality scores on stormwater management will not always indicate that a community is managing stormwater more soundly or effectively.

4.3.6.2 Reliability Threats

Reliability refers to the consistency, repeatability, and stability of measurements (Shadish et al., 2002). Reliability is perhaps one of the major threats of this study, especially with regard to plan quality evaluation. To maintain an inter-coder reliability and reduce personal bias in judgment, two scorers have evaluated all 42 local comprehensive plans. The plan indicators were pre-tested by the first scorer (the author) and re-tested by the second scorer using the same plan coding protocol. The percent agreement score, which is a generally accepted technique to measure inter-coder reliability in past plan evaluation studies, was computed through "ReCal," a Web-based tool (Freelon, 2010). As shown in Table 4.2, the overall average percent agreement score calculated from the double-coded data was about 83 percent. Generally, past plan quality evaluation studies considered a score higher than 80 percent as acceptable (Berke & Godschalk, 2009; Miles & Huberman, 1994).

Table 4.2. Percent Agreement Score of Each Plan Component

Plan component	Percent agreement score
Factual basis	90.48%
Goals and objectives	81.39%
Policies, tools, and strategies	80.27%
Coordination and cooperation	84.48%
Implementation	77.38%
Average	82.80%

To examine the level of inter-item consistency and reliability, Cronbach's Alpha test, which assesses the degree to which a set of indicators are correlated as a group, was conducted in this study. An α value in the range of 70 percent or above is typically considered as an adequate reliability by many researchers (Acock, 2012; Nunnally, 1978). Table 4.3 shows each plan component's Cronbach's alpha value.

Table 4.3. Cronbach's Alpha Value of Each Plan Component

Plan component	Cronbach's alpha
Factual basis	0.772
Goals and objectives	0.741
Policies, tools, and strategies	0.731
Coordination and cooperation	0.732
Implementation	0.690
Total Plan Quality	0.795

4.4 Results

4.4.1 Descriptive Statistics of Sustainable Stormwater Management Plan Quality

The descriptive analysis of total plan quality and each plan component provides a general understanding of which local jurisdictions have efficiently integrated the concepts and principles of sustainable stormwater management (Table 4.4). The average score of the 42 jurisdictions' comprehensive plan was 23.58 on a scale of 50, which signifies that communities have limited planning capacities and resources to prepare a stringent plan quality associated with sustainable stormwater management. The results also show that wide variations exist between the sample jurisdictions' plan quality scores, which implies that local jurisdictions possess different levels of capacities and put distinctive planning efforts into managing stormwater runoff and incorporating sustainable stormwater management principles/strategies into local comprehensive planning. Fifteen jurisdictions acquired scores between 7 and 20; 23 jurisdictions obtained scores between 20.1 and 30; and only four jurisdictions received scores higher than 30 (Figure 4.5). Specifically, Anne Arundel County, Maryland, earned the highest total plan quality score with 33.14, whereas Jefferson County, West Virginia, received the lowest score with 7.56. At the state level, the average score of Maryland (24.01 points) was the highest, followed by Virginia (22.30 points) and Pennsylvania (20.98 points). High plan quality scores imply that local planning capacities, efforts, as well as processes were sufficiently and strategically input by a local jurisdiction to manage stormwater in a sustainable manner. Total plan quality scores for each local jurisdiction are listed in Appendix D.

Table 4.4. Descriptive Statistics for Total Plan Quality and Plan Components

Plan components	Total indicators	Minimum	Maximum	Mean	Median	Standard deviation
Factual basis	9	2.78	7.78	5.43	5.83	1.24
Goals and objectives	11	0.91	8.18	4.70	4.55	1.59
Inter-organizational coordination	7	2.14	7.86	5.22	5.00	1.43
Policies, tools, and strategies	29	1.03	5.34	2.81	2.59	1.13
Implementation	6	0.83	8.33	4.19	3.75	2.23
Total plan quality	62	7.56	33.14	23.58	23.19	5.81

With regard to the five plan components identified in this study, the “factual basis” and “inter-organizational coordination and capabilities” components were relatively well mentioned within the plans sampled (mean score: 5.43 and 5.22, respectively). This indicates that the majority of local jurisdictions provided fairly strong background information about managing and controlling stormwater runoff. The “goals and objectives” and “implementation” components received scores slightly lower than

5.00, suggesting that communities have produced somewhat stringent long-term visions, broad goals, and measurable objectives for managing stormwater runoff with a moderate commitment to implementing the adopted plan in the near future. The "policies, tools, and strategies" component received the lowest mean score (2.81), which reveals that specific action strategies associated with stormwater management, such as regulatory, incentive, and land use planning tools, were weak and have not been concretely established to actualize a jurisdiction's goals and objectives.

4.4.2 Results for the Factors Influencing Surface Runoff

To identify the extent to which factors among four blocks of variables influence the two measures of runoff depth (mean annual runoff and mean annual peak runoff), multiple regression analysis was conducted. As previously mentioned in Section 4.3.4, sequential multiple regression analysis grouped the variables into four blocks due to the relatively small sample size compared to the number of independent variables. Regression models examined the distinctive impact of each block group on the variation in surface runoff depth. Planning capacity variables were first included in the model (Model 1), and then geographical, basin characteristic, and biophysical variables were sequentially entered into the next models. Only statistically significant variables in each model were finally included in a fully specified model. Each dependent variable's regression results are presented separately through tables 4.5 to 4.8.

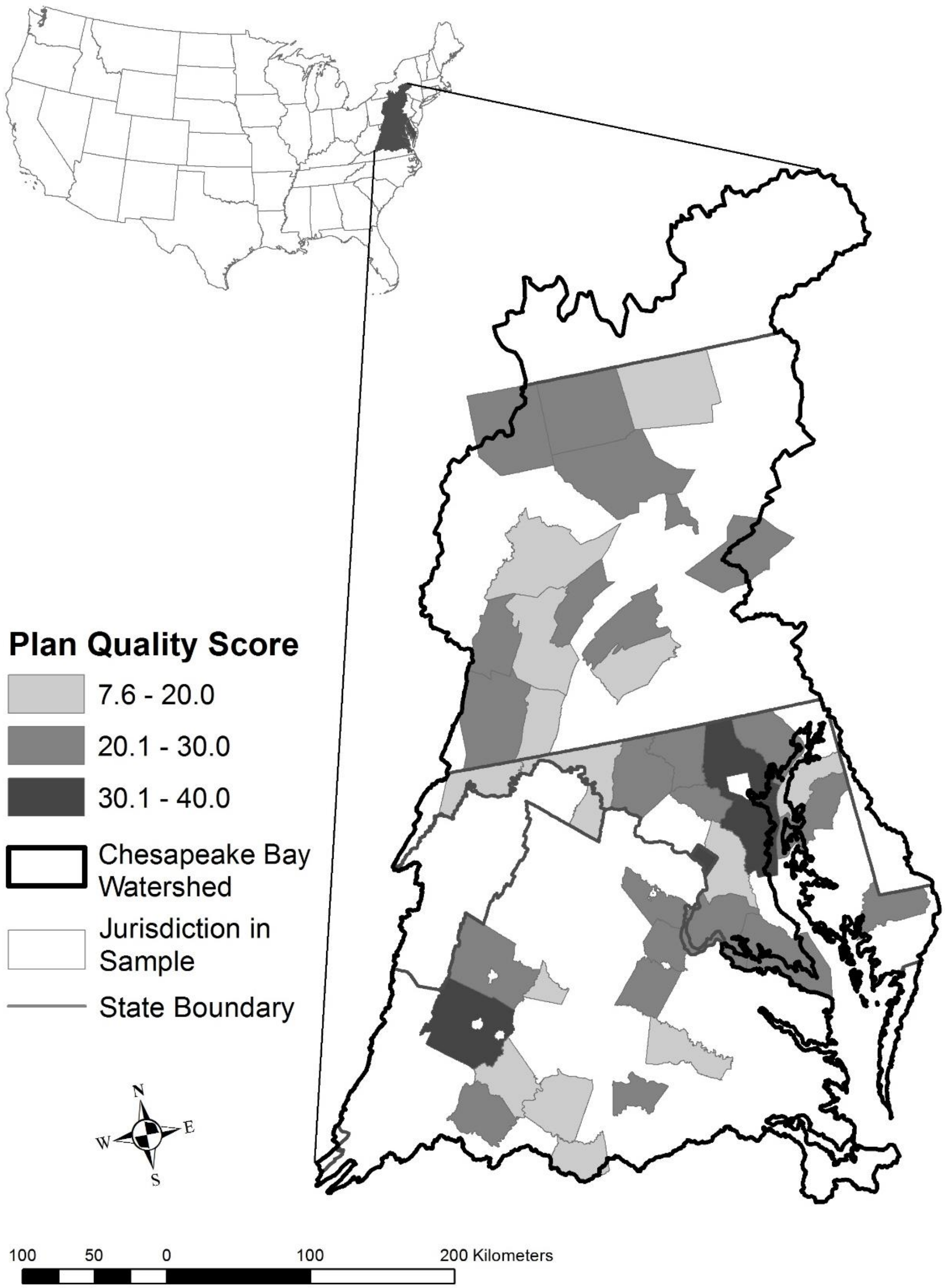

Figure 4.5. Plan Quality Scores by Local Jurisdiction

4.4.2.1 Regression Results of Mean Annual Runoff Depth

Model 1 (planning capacity variables) explained the variance of the mean annual runoff depth by about 8 percent, with an adjusted R^2 of 0.079. The results suggested that plan quality score and plan adopted year make statistically significant contributions to mean annual runoff depth. Specifically, plan quality score was positive and significant at the $p<0.01$ level. Plan adopted year, however, had a significant and negative impact on mean annual runoff as expected at the $p<0.05$ level. Although the effect of the number of planners and the existence of private consultants were not statistically significant, the direction of both variables followed the expected relationship.

Model 2 (planning capacity variables and geographical variables) explained about 17 percent of the variance in mean annual runoff depth. Through the correlation analysis (Appendix E), this study found that natural land cover and impervious surface were highly correlated (r= -0.730). Since the amount of impervious surface may represent the degree of urbanization and its impact on mean annual runoff depth provides more significant insights to local land use planners, natural land cover data were dropped in this model. Plan quality score, plan adopted year, and number of planners were statistically significant at the $p<0.1$ level. While plan quality score was positively associated with mean annual runoff depth, which had a sign opposite to the expected direction, plan adopted year and the number of planners had a negative impact on mean annual runoff depth, as expected. In addition, the percentage of impervious surface had a positive and statistically significant relationship with mean annual runoff depth at the $p<0.05$ level, which reacted in the expected direction. The association between the percentage of wetland and mean annual runoff was negative, as expected, but it was statistically insignificant.

Model 3 (planning capacity variables and basin characteristics variables) explained nearly 12 percent of the variance in mean annual runoff. Within the planning capacity variables, only the association between plan quality score and mean annual runoff depth was statistically significant at the $p<0.01$ level. The direction was again positive as opposed to the initial expectation. The other three planning factors had negative relationships with mean annual runoff depth, as expected, but were statistically insignificant. Average basin slope showed a positive and significant relationship with mean annual runoff depth at the $p<0.05$ level. The result corresponded with the findings of past relevant studies where steeper slopes generate more surface runoff. The association between the shape of basin (elongation ratio) and mean annual runoff depth was opposite to the expected sign but insignificant.

Model 4 (planning capacity variables and biophysical variables) accounted for approximately 46 percent of the variance of mean annual runoff depth. Within planning factors, plan adopted year and the number of planners had statistically significant effects on mean annual runoff depth at the $p<0.05$ level. Plan quality score was again positively associated with the dependent variable, but was not statistically significant. The involvement of private consultants was also positively associated with mean annual runoff depth, but was insignificant. Among the five biophysical variables, average monthly precipitation, the days of flash flood event, and natural drainage density were statistically significant. In particular, a unit increase in precipitation and the days of flash flood events had a positive effect on mean annual runoff depth, which was expected in the initial hypothesis. In contrast to the initial expectation, natural drainage density was negatively associated with mean annual runoff depth. The percentages of floodplain and saturated hydraulic conductivity (soil) were statistically insignificant and the directions were against the expected signs.

Model 5 (fully specified model) explained a significant portion (about 61 percent) of the variance in mean annual runoff depth. Eight variables that were statistically significant in each model were included in this model: plan quality score, plan adopted year, number of planners, impervious surface, average slope, precipitation, days of flash flood events, and natural drainage density. Within planning factors, all three variables continued to have the same signs on the relationships with mean annual runoff depth. However, only the number of planners had a negative and statistically significant impact on mean annual runoff depth, holding other variables constant. Plan quality score and plan adopted year were insignificant in this model. Impervious surface and average basin slope still had positive and significant associations with mean annual runoff depth at the $p<0.01$ level. Similar to the results of Model 4, precipitation, flash flood events, and natural drainage density were again statistically significant with mean annual runoff depth. Precipitation and flash flood events were still positively associated with mean annual runoff depth, while their degree of coefficients have been slightly shrunken. Natural drainage density also maintained negative relationship with mean annual runoff depth, but the strength of the coefficient increased.

Table 4.6 presents the standardized beta coefficient for each model indicating which variables most influence the degree of mean annual runoff depth. Overall, precipitation was the most powerful predictor in explaining the variance in mean annual runoff depth, followed by average slope, impervious surface, natural drainage density, number of planners, and number of flash flood events.

Table 4.5. Results of Regression Models (D.V.: Mean Annual Runoff Depth)

D.V.: Mean annual runoff depth	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)
Planning capacity variables (Baseline)					
Plan quality score	**0.0293*** (0.0100)**	**0.0183* (0.0100)**	**0.0262*** (0.0098)**	0.0136 (0.0084)	0.0077 (0.0072)
Plan year	**-0.0440** (0.0180)**	**-0.0318* (0.0181)**	-0.0303 (0.0188)	**-0.0230** (0.0088)**	-0.0093 (0.0127)
Number of planners	-0.0164 (0.0112)	**-0.0208* (0.0120)**	-0.0045 (0.1222)	**-0.0315** (0.0145)**	**-0.0146* (0.0082)**
Consultant	-0.1182 (0.0830)	-0.0600 (0.0810)	-0.1304 (0.0816)	-0.1069 (0.0718)	
Geographical variables					
Impervious surface		**0.0047** (0.0018)**			**0.0041*** (0.0013)**
Wetland		-0.0070 (0.0058)			
Basin characteristics variables					
Average slope			**0.0137** (0.0063)**		**0.0230*** (0.0044)**
Shape (Elongation ratio)			-0.0819 (0.3104)		
Biophysical variables					
Precipitation				**0.0026*** (0.0005)**	**0.0021*** (0.0003)**
Flash flood events (Days exceeding base discharge)				**0.0165*** (0.0058)**	**0.0087* (0.0051)**
Natural drainage density				**-0.2129** (0.1047)**	**-0.2928*** (0.0893)**
Floodplain				0.0007 (0.0095)	
Soil (Avg. K_{sat})				0.0137 (0.0096)	

Table 4.5. Continued

D.V.: Mean annual runoff depth	Model 1 Coefficient (Std. Err.)	Model 2 Coefficient (Std. Err.)	Model 3 Coefficient (Std. Err.)	Model 4 Coefficient (Std. Err.)	Model 5 Coefficient (Std. Err.)
Constant	**0.6573** (0.2622)**	**0.8789*** (0.2596)**	**0.6212** (0.3131)**	**-1.9852*** (0.5566)**	**-1.3035*** (0.4311)**
F ratio	2.58	3.60	2.64	8.10	15.74
Probability > F	0.0444	0.0037	0.0232	0.0000	0.0000
R^2	0.1286	0.2411	0.1890	0.5287	0.6561
Adj. R^2	0.0788	0.1741	0.1174	0.4635	0.6145
Root MSE	0.3437	0.3254	0.3364	0.2623	0.2224

Notes: N = 75; D.V.: Mean annual runoff depth; *: significant at .1 level; **: significant at .05 level; *: significant at .01 level**

Table 4.6. Results of Regression Models (Standardized Coefficients)

D.V.: Mean annual runoff depth	Model 1 Standardized Coefficient	Model 2 Standardized Coefficient	Model 3 Standardized Coefficient	Model 4 Standardized Coefficient	Model 5 Standardized Coefficient
Planning capacity variables					
Plan quality score	**0.4640*** **	**0.2898***	**0.4146*** **	0.2145	0.1235
Plan year	**-0.3795** **	**-0.2741***	-0.2616	**-0.2555** **	-0.0801
Number of planners	-0.1817	**-0.2317***	-0.0501	**-0.2721** **	**-0.1623***
Consultant	-0.1658	-0.0841	-0.1830	0.1499	
Geographical variables					
Impervious surface		**0.3366** **			**0.2970*** **
Wetland		-0.1427			
Basin characteristics variables					
Average slope			**0.2799** **		**0.4706*** **
Shape (Elongation ratio)			-0.0294		
Biophysical variables					
Precipitation				**0.6121*** **	**0.4994*** **
Flash flood events				**0.2671*** **	**0.1398***
Natural drainage density				**-0.1892** **	**-0.2601*** **
Floodplain				0.0068	
Soil (Avg. K_{sat})				0.1295	
Constant	**0.6573** **	**0.8789*** **	**0.6212** **	**-1.9852*** **	**-1.3035*** **
F ratio	2.58	3.60	2.64	8.10	15.74
Probability > F	0.0444	0.0037	0.0232	0.0000	0.0000
R^2	0.1286	0.2411	0.1890	0.5287	0.6561
Adj. R^2	0.0788	0.1741	0.1174	0.4635	0.6145
Root MSE	0.3437	0.3254	0.3364	0.2623	0.2224

Notes: N = 75; D.V.: Mean annual runoff depth; *: significant at .1 level; **: significant at .05 level; *: significant at .01 level**

4.4.2.2 Summary of Results on Mean Annual Runoff Depth

The impact of key variable, planning capacities, on mean annual runoff depth varied slightly in each model. Plan quality score was statistically significant from Models 1 to 3 and consistently had a positive relationship with mean annual runoff depth in all models. This finding does not support to the initial hypothesis that sub-basins of higher plan quality with regard to sustainable stormwater management will generate less mean annual runoff and mean annual peak runoff. Plan adopted year, number of planners, and involvement of consultants were all negatively associated with mean annual runoff depth, as initially expected. While, plan adopted year was statistically significant in Models 1, 2, and 4 and the number of planners was statistically significant in Models 2, 4, and 5, the involvement of consultants was insignificant in all models. This result supports the initial hypotheses that a sub-basin in a jurisdiction incorporating an up-to-date plan as well as with more planners' involvement while adopting a plan is likely to generate less mean annual runoff.

Within geographical variables, the association between impervious surface and mean annual runoff depth was positive and statistically significant in Model 2 and the fully specified model (Model 5). This relationship was expected because more urbanized areas have less permeable surfaces, and more developments lead to increased stormwater runoff. However, the coefficient was not as strong as to what I initially expected. Wetland was negative with respect to the relationship with mean annual runoff depth, but it was not statistically significant.

With regard to basin characteristics variables, average basin slope was statistically significant and positively associated with mean annual runoff depth as expected in the initial hypothesis. However, basin shape (elongation ratio) did not reveal a significant relationship with mean annual runoff depth and the direction was opposite to what I originally hypothesized.

Among biophysical variables, precipitation, flash flood events, and natural drainage density variables were statistically significant in Models 4 and 5. Both precipitation and flash flood events variables were positively associated with mean annual runoff depth, but coefficients were smaller than our initial expectation. The association between natural drainage density and mean annual runoff depth was negative in both models. However, the relationship was against the initial hypothesis. Floodplain and saturated hydraulic conductivity (soil) variables were neither significant nor reacted in the expected direction.

4.4.2.3 Regression Results of Mean Annual Peak Runoff Depth

Model 1 (planning capacity variables) explained about 25 percent of the variance in mean annual peak runoff depth. Among the four planning factors, plan quality score and involvement of consultants were statistically significant contributors to mean annual peak runoff depth. While plan quality score was significant at the $p<0.01$ level but in the positive direction, the involvement of consultants was significant at the $p<0.05$ level in the negative direction. Plan adopted year and the number of planners were not significant predictors of mean annual peak runoff depth.

Model 2 (planning capacity variables and geographical variables) explained over 46 percent of variation in mean annual peak runoff depth. Through the correlation analysis, we found that the natural land cover variable had a high correlation with impervious surface (r=-0.730) and so was dropped in this model. Impervious surface was positively associated with mean annual peak runoff depth and statistically significant at the $p<0.01$ level. Wetland appeared to significantly influence the mean annual peak runoff depth at the $p<0.05$ level in the negative direction. None of planning capacities variables were statistically significant in this model.

Model 3 (planning capacity variables and basin characteristics variables) explained about 35 percent of the variance in mean annual peak runoff depth. As with the results of Model 1, plan quality score and involvement of consultants were both statistically significant, whereas plan adopted year and number of planners were not significant predictors. Plan quality score was positive and significant at the $p<0.01$ level. The involvement of consultants was negative and statistically significant at the $p<0.1$ level. Basin shape (elongation ratio) strongly influenced the mean annual peak runoff and the relationship was statistically significant at the $p<0.01$ level. Average basin slope had an expected association with mean annual peak runoff depth but was statistically insignificant.

Model 4 (planning capacity variables and biophysical variables) explained nearly 42 percent of the variance in mean annual peak runoff depth. Plan quality score was again positive and significant at the $p<0.05$ level. The other three planning factors were not significant contributors of mean annual peak runoff depth. Within the four biophysical variables, average monthly precipitation, the percentage of floodplain, and saturated hydraulic conductivity (soil) made statistically significant contributions to mean annual peak runoff depth. Specifically, precipitation showed a positive and significant relationship with mean annual peak runoff depth at the $p<0.05$ level. The association between floodplain and mean annual peak runoff depth was opposite to the expected sign but statistically significant at the $p<0.01$ level. The coefficient of saturated hydraulic conductivity (soil) was negative but significant at the $p<0.01$ level. Natural drainage density had a positive relationship with mean annual peak runoff depth as expected, but it was statistically insignificant.

Model 5 (a fully specified model including variables of plan quality score, involvement of consultants, impervious surface, wetland, basin shape, precipitation, floodplain, and soil) explained a significant portion (about 65 percent) of the variance in mean annual peak runoff depth. Plan quality score was still positive but only significant at the $p<0.10$ level. The dummy variable of consultant was an insignificant contributor of the dependent variable. Impervious surface was again positive and significant at the $p<0.01$. Wetland had a negative coefficient but was statistically insignificant with mean annual peak runoff depth. Basin shape again had a high positive coefficient and remained statistically significant at the $p<0.01$ level. Similar to the results of Model 4, precipitation, floodplain, and saturated hydraulic conductivity (soil) were statistically significant with mean annual peak runoff depth. Precipitation had a general positive and significant ($p<0.05$) relationship with mean annual peak runoff depth. Floodplain and saturated hydraulic conductivity (soil) were both negatively associated with mean annual peak runoff depth and statistically significant at the $p<0.01$ level.

As far as the standardized beta coefficients are considered, impervious surface was the most significant predictor in explaining the variance in mean annual peak runoff depth, followed by floodplain, basin shape, precipitation, plan quality score, and soil (see Table 4.8).

Table 4.7. Results of Regression Models (D.V.: Mean Annual Peak Runoff Depth)

D.V.: Mean annual peak runoff depth	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)	Coefficient (Std. Err.)
Planning capacity variables (Baseline)					
Plan quality score	**0.0765*** (0.0240)**	0.0353 (0.0219)	**0.0728*** (0.0225)**	**0.0477** (0.0225)**	**0.0261* (0.0135)**
Plan year	-0.0146 (0.0438)	0.0320 (0.0391)	-0.0182 (0.0430)	-0.0045 (0.0391)	
Number of planners	0.0304 (0.0272)	0.0146 (0.0257)	-0.0264 (0.0283)	0.0345 (0.0247)	
Consultant	**-0.4098** (0.2013)**	-0.1934 (0.1751)	**-0.3498* (0.1870)**	-0.1566 (0.1997)	0.0085 (0.1545)
Geographical variables					
Impervious surface		**0.0172*** (0.0040)**			**0.0172*** (0.0031)**
Wetland		**-0.0275** (0.0126)**			-0.0100 (0.0120)
Basin characteristics variables					
Average slope			0.0035 (0.0144)		
Shape (Elongation ratio)			**2.5813*** (0.7112)**		**1.6231*** (0.5408)**
Biophysical variables					
Precipitation				**0.0029** (0.0013)**	**0.0020** (0.0010)**
Natural drainage density				0.4410 (0.2927)	
Floodplain				**-0.0863*** (0.0262)**	**-0.0834*** (0.0207)**
Soil (Avg. K_{sat})				**-0.0735*** (0.0266)**	**-0.0425*** (0.0264)**

Table 4.7. Continued

D.V.: Mean annual peak runoff depth	Model 1 Coefficient (Std. Err.)	Model 2 Coefficient (Std. Err.)	Model 3 Coefficient (Std. Err.)	Model 4 Coefficient (Std. Err.)	Model 5 Coefficient (Std. Err.)
Constant	**2.3389*** (0.6361)**	**3.1744*** (0.5616)**	0.9499 (0.7175)	0.3207 (1.5546)	0.5056 (1.2249)
F ratio	7.00	11.58	7.77	7.6	18.31
Probability > F	0.0001	0.0000	0.0000	0.0000	0.0000
R^2	0.2858	0.5054	0.4067	0.4795	0.6894
Adj. R^2	0.2450	0.4618	0.3544	0.4164	0.6517
Root MSE	0.8337	0.7039	0.7709	0.7329	0.5662
Notes: N = 75; D.V.: Mean annual peak runoff depth; *: significant at .1 level; **: significant at .05 level; *: significant at .01 level**					

Table 4.8. Results of Regression Models (Standardized Coefficients)

D.V.: Mean annual peak runoff depth	Model 1 Standardized Coefficient	Model 2 Standardized Coefficient	Model 3 Standardized Coefficient	Model 4 Standardized Coefficient	Model 5 Standardized Coefficient
Planning capacity variables (Baseline)					
Plan quality score	**0.4518*** **	0.2083	**0.4294*** **	**0.2748** **	**0.1543* **
Plan year	-0.0470	0.1032	-0.0586	0.1495	
Number of planners	0.1259	0.0605	0.1094	-0.0145	
Consultant	**-0.2145** **	-0.1012	**-0.1831* **	-0.0845	0.0045
Geographical variables					
Impervious surface		**0.4643*** **			**0.4634*** **
Wetland		**-0.2078** **			-0.0750
Basin characteristics variables					
Average slope			-0.0271		
Shape (Elongation ratio)			**0.3460*** **		**0.2176*** **
Biophysical variables					
Precipitation				**0.2518** **	**0.1776** **
Natural drainage density				0.1475	
Floodplain				**-0.3121*** **	**-0.3009*** **
Soil (Avg. K_{sat})				**-0.2597*** **	**-0.1497*** **
Constant	**2.3389*** **	**3.1744*** **	0.9499	0.3207	0.5056
F ratio	7.00	11.58	7.77	7.6	18.31
Probability > F	0.0001	0.0000	0.0000	0.0000	0.0000
R^2	0.2858	0.5054	0.4067	0.4795	0.6894
Adj. R^2	0.2450	0.4618	0.3544	0.4164	0.6517
Root MSE	0.8337	0.7039	0.7709	0.7329	0.5662
Notes: N = 75; D.V.: Mean annual peak runoff depth; *: significant at .1 level; **: significant at .05 level; *: significant at .01 level**					

4.4.2.4 Summary of Results on Mean Annual Peak Runoff Depth

With respect to the association between planning capacity factors and mean annual peak runoff depth, plan quality score was constantly positive and significant in all models except Model 2. The direction of this variable to mean annual peak runoff depth, however, was against the expected relationship. Involvement of consultants was negative and statistically significant only in Model 1 and 3. The negative direction demonstrates that the existence of private consultants while drafting a plan may have a significant impact on minimizing mean annual peak runoff, holding other variables constant. Both plan adopted year and number of planners were statistically insignificant in all models. Also, the directions of these two variables were unstable throughout the modeled results.

When it comes to geographical variables, impervious surface had a positive and statistically significant relationship with mean annual peak runoff depth in Models 2 and 5. This result coincides with our initial hypothesis and supports the previous literature in that the increase of impervious surfaces expands peak discharge by reducing time of concentration, baseflow, and infiltration ability (Arnold & Gibbons, 1996; Booth & Jackson, 1997; Schueler, 1994). However, compared to the findings of past relevant studies, the coefficient of impervious surface was not as strong as expected. Wetland was negatively associated with mean annual peak runoff depth in Model 2, but did not show significant result in Model 5. Although no serious multicollinearity was detected in Model 5, relatively high correlation between wetland and soil might be a possible reason for a reduced statistical effect on mean annual peak runoff depth.

Among two basin characteristics variables, only basin shape (elongation ratio) was positively and significantly associated with mean annual peak runoff depth in Models 3 and 5. In specific, basin shape was the most powerful predictor in explaining the variance of mean annual peak runoff depth. Average basin slope, however, was not statistically significant. The direction of both variables relative to the dependent variable followed the expected signs.

Biophysical factors are highly related to runoff generation. Average monthly precipitation, the percentage of floodplain, and saturated hydraulic conductivity (soil) had statistically significant effects on mean annual peak runoff depth in Models 4 and 5. As the relationship was generally expected and well supported by previous literature, the results suggest that more precipitation led to greater amounts of mean annual peak runoff. Surprisingly, the percentage of floodplain had a negative impact on mean annual peak runoff depth, which was opposite to the expected direction. This result may possibly be explained because land developments within the 100-year floodplain are well regulated by local governments, and thus the amount of excessive runoff might be minimized. Saturated hydraulic conductivity (soil) displayed a negative relationship with mean annual peak runoff depth. This result supports that sub-basins containing a higher percentage of porous soils may generate less mean annual peak runoff. Natural drainage density had a positive but statistically insignificant relationship with mean annual peak runoff depth.

4.4.3 Overall Summary of Regression Results

The findings from regression analyses on mean annual runoff depth and mean annual peak runoff depth revealed some similarities as well as differences. Based on the modeled results, the following outcomes are highlighted.

First, the coefficients of determination differed by each model and dependent variable. While the adjusted R^2 values for mean annual runoff depth models (Models 1-4) ranged from 0.079 to 0.464, with the average value of 0.208, values for the mean annual peak runoff depth models ranged from 0.245 to 0.462, with the average value of 0.302. Thus, independent variables seem to better explain the models for mean annual peak runoff depth. However, the R^2 values of the fully specified models (Model 5) were very similar for both dependent variables (0.612 and 0.652, respectively).

Second, when it comes to the planning capacity variables, plan quality score was not an influential predictor of both dependent variables. Although plan quality score was statistically significant in several models, its degree of coefficients was relatively weak to explain the variance of dependent variables. Furthermore, plan quality score had a positive impact on both runoff variables. This relationship is opposite to the initial hypothesis that sub-basins of higher plan quality with regard to sustainable stormwater management would generate less mean annual runoff and mean annual peak runoff. In the fully specified model, plan quality score showed a statistically significant relationship only with mean annual peak runoff depth. The number of planners while drafting a plan had a negative and significant relationship with mean annual runoff depth in the fully specified model. This result supports the initial assumption that involving more number of planners during the plan adoption process will lower mean annual runoff depth. However, it was not statistically significant in any of the regression models when the dependent variable was mean annual peak runoff depth. Other planning capacity variables, plan adopted year and the existence of consultants, did not show any statistically significant impacts on both dependent variables in the fully specified models.

Third, among two geographical variables, impervious surface had positive and significant effects on both dependent variables in the fully specified models. Specifically, a 1 percent increase in impervious surface was associated with 0.005 mm increase in mean annual runoff depth. Moreover, for every 1 percent increase in impervious surface, mean annual peak runoff depth can be increased by 1.72 percent. This result supports the initial hypothesis that sub-basins having more impervious surfaces will generate greater amounts of stormwater runoff. Specifically, impervious surface was the most powerful predictor that explained the variance of mean annual peak runoff depth. Although the percentage of wetland area had a negative relationship with both dependent variables as expected, it was only statistically significant in Model 2 of mean annual peak runoff depth.

Fourth, this study identified that two basin characteristics variables, average basin slope and basin shape (elongation ratio), have contributed differently to the dependent variables. As we expect steeper basin slopes to increase both runoff depths, the coefficients of average basin slope displayed positive directions, but it was only statistically significant to mean annual runoff; whereas, basin shape was only statistically significant with mean annual peak runoff. In particular, one unit increase in elongation ratio was associated with 162.31 percent increase in mean annual peak runoff depth.

Finally, five biophysical variables reacted differently to dependent variables. The average monthly precipitation was statistically significant and positively associated with both dependent variables. However, mean annual runoff depth had significant relationships only with the days of flash flood events and natural drainage density, whereas mean annual peak runoff depth had significant relationships with the percent floodplain area and saturated hydraulic conductivity. Interestingly, results of this study showed unexpected directions for two variables, natural drainage density and the percent floodplain area. Contrary to our initial hypothesis, natural drainage density had a negative effect on mean annual runoff depth, meaning that one ratio increase in natural drainage density resulted in 0.293mm decrease in mean annual runoff depth. Additionally, for every 1 percent increase in floodplain area, mean annual peak runoff depth decreased by 8.34 percent. A possible explanation for these relationships is that sub-basins with a higher greater natural drainage density may include bigger floodplains. If a community has effectively managed their floodplains by prohibiting developments within the floodplain, mean annual runoff and peak runoff may significantly decrease with the locality's planning effort. This result coincides with the finding of previous study (Kang, 2009), which discovered that stream length has negative relationship with insured flood damage. However, results support the initial expectations that more days of flash flood events as well as higher saturated hydraulic conductivity resulted in generating less surface runoff.

4.5 Discussion and Policy Implications

4.5.1 Discussion of Descriptive Analysis

The majority of local governments had relatively weak sustainable stormwater management plan quality, with a mean score of 23.58 on a scale of 50. There is a significant lack of planning efforts and limited awareness of local planners to transform the key principles of sustainable stormwater management into their existing planning frameworks. Although several state stormwater management acts within the Mid-Atlantic region encouraged local municipalities to adopt and enforce stormwater management regulations, adopting consistent stormwater management ordinances and regulations was not mandatory. Thus, local jurisdictions had low motivation and unclear direction in taking actions to control stormwater runoff in a sustainable manner. However, when we look at the average plan quality score of three states in the sample, jurisdictions in Maryland had the highest average plan score (mean score: 24.01), followed by Virginia (mean score: 22.30) and Pennsylvania (mean score: 20.98). From the early 1980s, the State of Maryland had made arduous efforts to manage stormwater runoff compared to other states. In 2000, the state even developed the Maryland Stormwater Design Manual to support localities in controlling both quantity and quality of runoff. Thus, this study's results underpin the importance of state efforts and top-down approaches, which can be powerful motivations for local communities to adopt certain policies even though the issues are not considered in the forefront at the moment. This study also confirms findings of prior studies that state-level planning programs may positively impact plan quality toward sustainable stormwater management and suggests high-level governments to prepare state- or nation-wide comprehensive planning programs in a way that enhances local plan quality. Specifically, through the regional partnerships, such as the Chesapeake Bay Program, various federal, state, and local stakeholders and organizations can more actively cooperate with each other, share detailed water quantity and quality information, and develop concrete and measureable stormwater management policies and site designs that could effectively guide the local government partners. Most importantly, local planners should utilize these resources to reinforce their planning abilities.

In terms of plan components, local comprehensive plans in the study sample have provided relatively strong factual bases associated with stormwater management (average score: 5.43). While plan indicators have successfully incorporated broad elements of sustainable stormwater management concepts, specific inventories related to controlling and managing stormwater runoff were rarely considered. Thus, more detailed informational bases directed toward stormwater quantity and quality issues should be included in a plan since local planners establish efficient policies based on a solid factual basis. In addition, local jurisdictions need to take advantage of existing regional- and state-level environmental information in enhancing the quality of local plans. Adopting the abundant environmental and water-related information from the higher-level government entities will be the quickest way for local jurisdictions to improve the factual basis component without significant efforts and financial burdens.

Local plans also showed relatively good coordination and coping capabilities for trans-boundary issue (average score: 5.22). The existence of the regional partnership (e.g., Chesapeake Bay Program) and three adopted agreements of the Chesapeake Bay watershed region in 1983, 1987, and 2000 may persuasively explain why the inter-organizational coordination component received such a relatively high score. However, the lack of intra-jurisdictional coordination between municipalities and departments is still a key barrier for effective stormwater management. By embracing planning approaches and water-related engineering approaches, more sustainable stormwater perspectives can be applied before any new or redevelopment processes begin (Cettner et al., 2013). Given the fact that the comprehensive plans are usually developed by the lead of local planners, cooperation among organizations (especially with the water departments and utilities) is highly recommended.

Goals and objectives scored slightly lower than 5 on a scale of 10 (average score: 4.70). Similarly to the problem noted in the factual basis component, emphasis on more specific goals and objectives toward managing stormwater runoff could enhance the quality of local plans. Particularly, up-to-date site development techniques, such as LID and diverse BMPs, need to be mentioned more frequently with detailed explanations in a plan, and linked to measurable objectives, to provide an ideal platform for developing effective policies and action strategies.

The implementation component, which is one of the essential parts within a local plan to actualize certain policies into practice, was not sufficiently recognized by local jurisdictions (average score: 4.19). As Brody and Highfield (2005) identified in their study, a high correlation exists between the implementation plan component and the degree of plan implementation. While many jurisdictions have successfully mentioned general implementation indicators, such as clear timeline, regular plan updates, and designation of responsibilities for actions, within their plans, they often fail to highlight stormwater sustainability as a priority in implementation and do not include an efficient stormwater monitoring system. For local planners to be proactive rather than reactive to stormwater-related issues, both quantity and quality of runoff should be continuously monitored to better reflect changing environmental conditions. Through a thorough monitoring system, more stringent linkages can be built between plan intent and plan implementation.

The policies, tools, and strategies component was the weakest element in the local comprehensive plans (average score: 2.81). The results reveal that many local jurisdictions tend to rely on traditional land use planning toolkits, such as land acquisition tools (e.g., open space preservation and conservation easement) and land regulatory tools (e.g., setbacks and buffer zones, restrictions on local vegetation and forest removal, development away from floodplains). Incentive-based tools and awareness tools were occasionally adopted by local planners. Since providing incentives and increasing awareness are the most cost-effective approaches for local governments to manage stormwater, further adoption of these planning tools is necessary in addition to conventional planning measures. With respect to structural tools, the terms innovative practices and BMPs were often mentioned in the sampled plans, whereas, newly emerging techniques, such as LID techniques and green infrastructure, were rarely mentioned. This suggests local governments might do well by adopting more newly emerging practices associated with sustainable stormwater management, which are known to be more efficient in controlling stormwater runoff.

4.5.2 Discussion of Regression Analysis

The explanatory results of this study indicated that several contextual variables may affect both mean annual runoff depth and mean annual peak runoff depth. The importance of the findings is that surface runoff can be influenced by the efforts and capacities of local planning.

First, plan quality score had a positive impact on both mean annual runoff depth and mean annual peak runoff depth. While plan quality score was statistically significant only in the fully specified model of mean annual peak runoff depth, it showed positive relationships with both dependent variables in most regression models. These results counter the initial expectations and suggest that possessing a high-quality plan does not always contribute to minimizing surface runoff. A possible explanation for this relationship may stem from several reasons. Although a jurisdiction develops a stringent comprehensive plan incorporating various policies and action strategies associated with stormwater management, those policies may not be implemented in practice. Thus, state and local agencies are strongly recommended to develop a plan implementation evaluation system that assesses whether plan outcomes conform to the initial intent of a plan (Brody & Highfield, 2005). For example, they might adopt the methodology that Laurian et al. (2004, 2010) used to identify whether land development permitting processes followed a plan's development policies. Such plan implementation evaluation systems may also play an important role in regular plan updates by discerning how certain policies have been actually implemented.

Second, jurisdictions that have frequently experienced damage due to flash flooding or excessive runoff may have already recognized their vulnerability to stormwater runoff, and thus have integrated diverse stormwater management policies and tools into their comprehensive plans beforehand. If this is the case, plan quality score will be a reactive action to the previous flooding experiences. As a result, even though a sub-basin is included in a jurisdiction that has a high-quality plan, the area may continuously produce greater amounts of runoff compared to sub-basins that have historically generated low volumes of stormwater runoff.

Finally, both mean annual runoff and mean annual peak runoff may be significantly influenced by upstream human disturbances. Although the sampled sub-basins were delineated based on the topography and flow direction and accumulation, upstream development pressures may considerably impact the quantity and quality of interconnected downstream flow. Therefore, if an upstream jurisdiction has a poor quality of stormwater management plan, a downstream sub-basin may generate significant amounts of surface runoff even though it is located in a jurisdiction that has a high-quality plan.

Taking into account the above interpretations, further research should carefully interpret the relationship between plan quality and surface runoff generation. In addition, decision-makers should certainly not underestimate the power of a comprehensive plan. Because a comprehensive plan is a long-range policy document that guides a community's future development, policy implementation effects may take some time to show up. Communities that consider only immediate and short-term concerns of mitigating stormwater runoff without long-term visions, goals, objectives, and action strategies will ultimately fail to manage stormwater sustainably. Thus, local planners and decision-makers should continuously place significant contributions on stormwater management in plan documents. Also, through periodical amendments of a plan, they should monitor and update whether specific policies have been successfully implemented.

The number of planners became a significant negative contributor of generating mean annual runoff, indicating that sub-basins included in jurisdictions that had more planners devoted while writing a plan may produce less mean annual runoff. This result follows the past studies' endorsements and initial hypothesis of this study that when more qualified planners participate in development of a comprehensive plan, it may lead to a better-quality of plan and enhance the plan's implementation due to more planning efforts and technical expertise devoted during the plan adoption process. Although the effect of number of planners on mean annual runoff depth was minimal, with a coefficient of 0.015, considering the average mean annual runoff depth (1.34mm), the impact can be significant when a jurisdiction hires multiple planners. The average number of planners in the sampled jurisdictions was 5.75 persons. In addition, as shown in the correlation matrix (Appendix E), there is a significant and negative relationship between the number of planners and the existence of private consultants. This indicates that local jurisdictions that have higher number of planners were likely to avoid (or not need to) hiring private consultants while developing a plan. Since no statistically significant association exists between the involvement of consultant and mean annual runoff depth, local governments may benefit in minimizing average runoff from bringing in more planners rather than employing private consultants while adopting the comprehensive plan. Moreover, while the regression results were statistically insignificant, the findings suggest that sub-basins incorporating more recently updated comprehensive plans may experience less surface runoff. The latest information and circumstances can be included in more recent and regularly updated plans, thus encouraging local planners to reflect up-to-date techniques within the action strategies.

Impervious surfaces, which accounted for 21.6 percent of land cover on average in the study area, increased both mean annual runoff depth and mean annual peak runoff depth: a 1 percent increase in the impervious surface resulted in 0.004mm increase in mean annual runoff depth and 1.72 percent increase in mean annual peak runoff depth, holding other variables constant. Although human developments caused by urbanization are an irresistible trend, local policy-makers and watershed planners should locate development strategically by determining which watersheds should be further regulated from the increased impervious surfaces. Thus, local/state planners and agencies are strongly recommended to monitor the spatial distributions and cumulative impacts of impervious land covers in order to effectively control the excessive runoff that might be caused from indiscriminate land developments (Brody et al., 2007). In addition, BMPs and LID practices should be installed in places where the percentage of impervious surface is high to efficiently manage runoff and prevent flash flooding events. These kinds of proactive planning approaches may also lead local governments to save initial construction and maintenance costs since on-site source control practices are more cost-effective than conventional drainage systems (USEPA, 2007).

4.6 Conclusions

This study identified 42 local jurisdictions' comprehensive plans have insufficiently integrated the principles of sustainable stormwater management, but large variation in plan scores existed across the sampled communities. In addition, this study discovered that local planning and other contextual factors may significantly influence mean and peak annual runoff in the Chesapeake Bay watershed. By far, a point increase in plan quality score would increase both mean and peak runoffs, inferring that the majority of local governments may already recognize the significance of stormwater runoff, and thus substantially incorporate concepts of sustainable stormwater management in their plans. When more planners devoted to the process while adopting a plan, sub-basins generated less mean runoff. The percentage of impervious surface and the average monthly precipitation increased both mean and peak runoffs. Interestingly, average basin slope, days of flash flood events, and natural drainage density impacted only on mean runoff; while basin shape (elongation ratio), percentage of floodplain area, and saturated hydraulic conductivity had associations solely with peak runoff.

While the findings of this study supported efforts to better understand the relationship of local planning capacities and the generation of mean/peak runoff, several limitations do exist and further research should be pursued on several fronts.

First, due to the complexity of study area selection criteria and processes, a relatively small number of samples, 75 sub-basins, was finally chosen for this study. This is a significant threat to sound statistical conclusions because of limited statistical power. Although more than 1,500 sub-basins were delineated based on the USGS gauge stations, a number of gauge stations had missing data during the study period and most sub-basin boundaries did not overlap the political boundary by more than 80 percent. Moreover, sub-basins were chosen only where local jurisdictions adopted their comprehensive plans from 2000 to 2010. Further studies should increase the sample size by employing an alternative way of representing jurisdictions by watersheds, such as the weighting approach that Brody et al. (2004) applied in their study. In addition to the weak statistical power, the findings should be generalized to other areas with care, especially where natural and built environments have dissimilar patterns since sub-basins only within the Mid-Atlantic region were examined in this study.

Second, the existing datasets for streamflow have limitations. As mentioned above, several monthly flow records were missing in the gauge stations, which made it difficult for this study to develop a threshold in choosing the study sample: sub-basins that had more than 90 percent of records during four years of the study period. To examine more accurate relationships between specific factors and surface runoff generation, future studies should be conducted by selecting sub-basins that have fully recorded datasets of streamflow. Furthermore, if the USGS can provide additional records such as flooding level for each gauge station, future research may use more reliable data, which can be more representative for flash flooding.

Third, temporal limitations exist for runoff and precipitation data. The data in this study were examined on an annual basis. However, the amount of runoff (dependent variable) and precipitation (biophysical variable) vary significantly by each month or season. For example, this study ruled out hydrological fluctuations that may be caused by snowmelt. Further studies should thus consider temporal impacts of surface runoff, precipitation, and other natural environmental attributes.

Fourth, the four planning factors used in this study may not substantially represent the entire local planning efforts and capacities. Because this study did not conduct surveys or interviews with planning staff and community leaders, critical information such as budgets for stormwater management, decision-maker's leadership, plannerss commitment, and public participation level was not collected. The variation of surface runoff generation could be more thoroughly explained by planning factors when this information is included and measured in the future.

Fifth, examining the implementation effects of a plan quality score as well as other planning capacity variables can be impeded due to the complexity of planning processes and hydrologic responses. Sub-basins that have relatively high-quality stormwater management plans tend to be under high development pressures, and thus they may generate more runoff. As the results from previous studies have shown, increased impervious surfaces caused by urbanization produce excessive runoff and the hydrologic attributes greatly change as imperviousness increases (Booth & Jackson, 1997; Braden & Johnston, 2004; Paul & Meyer, 2001; Schueler, 1994). However, urbanized jurisdictions are more likely to have higher plan quality because of greater planning capacities as well as financial and technical resources. This kind of paradoxical relationship between the development and planning processes in relationship to hydrologic responses still remains in this study and could impede examining the implementation effect of plan quality score on surface runoff. While this study indirectly attempted to examine the implementation effect of planning factors on surface runoff generation, additional research should further assess whether plan outcomes conform to the initial intent of a plan.

Finally, this study attempted to examine whether the quality of comprehensive plans has any associations with surface runoff by considering the plans adopted/amended between 2000 and 2010 and mean annual runoff/peak runoff depths from 2011 to 2014. However, the time interval might be too short to attest to the implementation impact of adopted policies and strategies, especially for plans that were updated closer to 2010. In addition, unavoidable limitations exist in determining when the policies will be effectively implemented in practice. To account for these temporal dimension issues and explain the causal relationship between independent and dependent variables, longitudinal analysis or panel analysis should be performed in future research rather than cross-sectional analysis if data are available. Particularly, panel analysis may better explain whether planning capacities have implementation effects in surface runoff by looking at the percent change of two distinct periods.

5. CONCLUSIONS

5.1 Summary

In contrast to large-scale flooding caused by hurricanes and extreme rainfalls, stormwater runoff and/or flash flooding can be more effectively controlled at the local level. Specifically, through strategic comprehensive plans with appropriate stormwater management practices as well as sufficient capabilities of local governments, adverse impacts from excessive runoffs can be significantly reduced. Section 3 examined the ability of local jurisdictions to implement the sustainable stormwater management principles in local comprehensive plans. The plan quality evaluation protocol that was developed in this study revealed the strengths and weaknesses of current plans aimed at achieving sustainable stormwater management. The results from the multivariate regression analysis suggested to local jurisdictions and planners which factors they should consider to improve stormwater management plans and how they should improve existing policies and strategies. Section 4 focused on identifying the implementation effects of local plan quality and planning capacity on annual mean/peak runoff reduction through multivariate regression analyses at the watershed level. The study investigated the degree of association of planning factors and other contextual variables with annual mean and peak runoff.

In Section 3, the findings showed that local jurisdictions in the Chesapeake Bay watershed have relatively weak plan qualities toward achieving sustainable stormwater management, but large variation in the plan scores existed across the communities. The local planners' significant lack of planning efforts and limited awareness was discovered through incorporating key principles of sustainable stormwater management into the existing planning framework. Among the three states, local jurisdictions in Maryland, which had put a significant emphasis on managing stormwater at the regional level from the past, received the highest average plan quality score. This implies that top-down approaches provide a powerful motivation for local communities to adopt certain policies. With respect to the performance of plan indicators, local plans in general had provided relatively stringent fundamental information about stormwater management and highlighted the importance of coordination and coping capabilities for a trans-boundary issue. However, they paid less attention to setting goals/objectives and in implementing action strategies. Moreover, a majority of the plans failed to address specific stormwater management policies, tools, and strategies. Most plan indicators included more general environmental elements than specific inventories that were directly related to controlling stormwater runoff. Thus, the results suggest that localities should integrate both broad and specific strategies of sustainable stormwater management into their comprehensive plans. The regression results show that local plan quality can be driven by the adopted year of a plan, the percentage of impervious surface, and past flooding experience. Specifically, jurisdictions that are more urbanized and have recently updated their local plans tend to score higher, while jurisdictions that have historically experienced more flooding events were less likely to generate high-quality plans.

In Section 4, the findings revealed that plan quality scores were positively associated with both mean and peak annual runoff. This contrasts with the initial hypothesis that sub-basins with higher quality plans will generate less surface runoff. As discussed in Section 4.5.2, several possible interpretations may explain the relationships of the two variables. In addition, the results show that sub-basins included in jurisdictions that had more assigned planners during the plan adoption process generated less mean annual runoff. While the regression results were statistically insignificant, the findings also suggest that sub-basins incorporating more recently updated comprehensive plans may experience less surface runoff. However, the two variables noted above were not statistically significant in all regression models when the dependent variable was peak annual runoff. The involvement of private consultants was not statistically significant in the fully specified model of peak annual runoff, as well as all models of mean annual runoff, even though the directions were what I initially expected (negative).

5.2 Policy Recommendations

5.2.1 Need More State Efforts toward Stormwater Management

This study confirms the findings of prior research that state-level planning programs may positively impact plan quality for sustainable stormwater management and suggests that high-level governments should prepare stateside or nation-wide comprehensive planning programs as a way to enhance local plan quality. Specifically, through a regional partnership, such as the Chesapeake Bay Program, various federal, state, and local stakeholders and organizations should actively cooperate with each other, share detailed water quantity and quality information, and develop concrete and measureable stormwater management policies and site designs that could effectively guide the associated local governments. Most importantly, local planners should utilize these resources to reinforce their planning abilities.

5.2.2 Enhance Plan Quality Associated with Stormwater Management

Although this study may not support the initial expectation that higher plan quality will significantly contribute to the reduction of surface runoff, decision-makers should not underestimate the power of a comprehensive plan. Since a comprehensive plan is a long-range policy document that guides a community's future development, policy implementation effects may take some time to be demonstrated in practice. Implementation involves complex processes, especially with regard to the challenge of surface runoff, which can be caused by diverse natural and built environment conditions. Thus, plans and policies should be continuously monitored by local planners with an adaptive approach. While this study used the plan quality score as a proxy to examine the implementation effect of the initial intent of a plan, future studies need to conduct a conformity research and assess whether plan outcomes conform to the initial goals, objectives, and strategies in a plan (Deyle et al., 2008).

As discussed in Section 3, planners should regularly update their comprehensive plans and devote significant effort during the planning process since those planning capacities play an important role in enhancing the quality of local plans. The latest information and circumstances should be incorporated into the latest, regularly updated plans, to reflect up-to-date techniques within the action strategies. Although urbanized areas tend to create higher quality plans because of relatively affluent technical and personnel resources, they are also more vulnerable to excessive stormwater runoffs, due to a higher percentage of impervious surfaces. Thus, their development policies and decisions should be carefully made when choosing what areas to develop and protect in order to alleviate adverse impacts from flash flooding. Learning about historical hazard experiences leads to a greater awareness and understanding of sustainable stormwater management. This knowledge can help to plan communities that are more resilient to excessive runoff, and also leads to higher-quality plans.

5.2.3 Increase Awareness of Sustainable Stormwater Management

Increasing awareness is one of the most essential processes when adopting a sustainable stormwater management plan (WERF, 2010). By providing more incentives and financial supports, higher levels of government should encourage localities to emphasize preparation for damage associated with stormwater runoff and enhanced awareness of integrating sustainable stormwater management principles into local action strategies. To further increase the awareness and understanding of sustainable stormwater management to local plan-makers, more training and technical efforts, such as lectures from water professionals, should be provided.

Education and outreach programs encourage diverse residents to participate in the decision-making process. Adequate public support and consensus results in higher quality plans that can be implemented in the real world (Brody, 2008; Kaplowitz & Lupi, 2012). Using various awareness instruments such as training workshops, public meetings, printed materials, school education programs, and web interfaces may increase public awareness to influence developers and residents to adopt sustainable stormwater management practices (Brody et al., 2010). Setting educational signage where LID practices are performed may also inform the public by providing actual visual examples (WERF, 2010).

5.2.4 Reduce Runoff through Land Use Planning

As discussed above, highly developed areas are more at risk from flash flooding due to a higher percentage of impervious surfaces. This study also revealed that a percentage increase in impervious surface results in greater amounts of mean and peak annual runoffs. Although planners may not stop the growth trend of a community, local policy makers and watershed planners should strategically locate developments by continuously monitoring the land use/land cover change. Specifically, the findings strongly recommend that they monitor the spatial distributions and cumulative impacts of impervious land covers in order to effectively control the excessive runoff that might be caused from indiscriminate land developments (Brody et al., 2007). Land-use regulations and incentives such as transfer of development rights, cluster zoning, conservation easements, density bonuses, and urban growth boundaries could be productive measures to preserve natural land covers and minimize damage from flooding (Brody et al., 2006). In addition, local jurisdictions should install stormwater BMPs and

LID practices where the percentage of impervious surface is high. Locating these practices in adequate places will help to manage runoff more efficiently by slowing down the runoff and increasing infiltration capacities. Such proactive planning approaches may also benefit local governments in reducing the initial construction and maintenance costs, since on-site source control practices are more cost-effective than conventional drainage systems (USEPA, 2007).

REFERENCES

Acock, A. (2012). *Gentle introduction to Stata*. (3rd ed.). College Station, TX: STATA Press.

Adams, B. J., & Papa, F. (2000). *Urban stormwater management planning with analytical probabilistic models*. West Sussex, UK: John Wiley & Sons, Inc.

Akpinar, A. (2013). Assessing the associations among green space type, structure, general mental health and general health employing the BRFSS and the US national land cover data. (Ph.D.), Interdisciplinary Design Institute, Washington State University, Pullman, WA.

American Planning Association (APA). (2000). *Policy guide on planning for sustainability*. Retrieved Dec. 10, 2013, from https://www.planning.org/policy/guides/adopted/sustainability.htm

American Planning Association (APA). (2002a). *Policy guide on water resources management*. Retrieved Dec. 10, 2013, from https://www.planning.org/policy/guides/adopted/waterresources.htm

American Planning Association (APA). (2002b). *Policy guide on wetlands*. Retrieved Dec. 10, 2013, from https://www.planning.org/policy/guides/adopted/wetlands.htm

American Planning Association (APA). (2012). *Policy guide on smart growth*. Retrieved Dec. 10, 2013, from https://www.planning.org/policy/guides/adopted/smartgrowth.htm

Arnold, C. L., & Gibbons, C. J. (1996). Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association, 62*, 243–258.

Atlanta Regional Commission (ARC). (2001). *Georgia stormwater management manual*. (1st ed.). (August, 2001). Retrieved Nov. 11, 2013, from http://atlantaregional.com/environment/georgia-stormwater-manual

Aytur, S. A., Satinsky, S. B., Evenson, K. R., & Rodriguez, D. A. (2011). Pedestrian and bicycle planning in rural communities: Tools for active living. *Family & Community Health*, *34*(2), 173-181.

Baer, W. C. (1997). General plan evaluation criteria: An approach to making better plans. *Journal of the American Planning Association, 63*(3), 329-345.

Baker, I., Peterson, A. Brown, G., & McAlpine, C. (2012). Local government response to the impacts of climate change: An evaluation of local climate adaptation plans. *Landscape and Urban Planning*, *107*(2), 127-36.

Barbosa, A., & Hvitved-Jacobsen, T. (2001). Infiltration pond design for highway runoff treatment in semiarid climates. *Journal of Environmental Engineering, ASCE 127*(11), 1014-1022.

Barbosa, A., Fernandes, J., & David, L. (2012). Key issues for sustainable urban stormwater management. *Water Research, 46*(20), 6787-6798.

Bassett, E., & Shandas, V. (2010). Innovation and climate action planning-perspectives from municipal plans. *Journal of the American Planning Association, 76*(4), 435-50.

Beatley, T. (1998). The vision of sustainable communities. In R. J. Burby (Ed.), *Cooperating with nature: Confronting natural hazards with land use planning for sustainable communities* (pp. 233-261). Washington, DC: Joseph Henry Press.

Bell, F. G. (2004) *Engineering geology and construction*. New York: Spon Press.

Benedict, M., & McMahon, E. (2006). *Green infrastructure: Linking landscapes and communities*. Washington, DC: Island Press.

Berger, K. P., & Entekhabi, D. (2001). Basin hydrologic response relations to distributed physiographic descriptors and climate. *Journal of Hydrology, 247*(3-4), 169-182.

Berke, P., & Beatley, T. (1992). A national assessment of local earthquake mitigation: Implications for planning and public policy. *Earthquake Spectra, 8*(1), 1-15.

Berke, P. (1994). Evaluating environmental plan quality: The case of planning for sustainable development in New Zealand. *Journal of Environmental Planning and Management, 37*(2), 155-169.

Berke, P., & French, S. (1994). The influence of state planning mandates on local plan quality. *Journal of Planning, Education and Research, 13*(4), 237-250.

Berke, P., Roenigk, D., Kaiser, E., & Burby, R. (1996). Enhancing plan quality: Evaluating the role of state planning mandates for natural hazard mitigation. *Journal of Environmental Planning and Management, 39*(1), 79-96.

Berke, P., Dixon, J., & Ericksen, N. (1997). Coercive and cooperative intergovernmental mandates: A comparative analysis of Florida and New Zealand environmental plans. *Environment and Planning B - Planning & Design, 24,* 451-468.

Berke, P. Crawford, J., Dixon, J., & Ericksen, N. (1999). Do cooperative environmental planning mandates produce good plans? Empirical results from the New Zealand experience. *Environment and Planning B, 26*(5), 63-664.

Berke, P., & Conroy, M. (2000). Are we planning for sustainable development? An evaluation of 30 comprehensive plans. *Journal of the American Planning Association, 66*(1), 21-33.

Berke, P. (2002). Does sustainable development offer a new direction for planning? Challenges for the twenty-first century. *Journal of Planning Literature, 17,* 21-36.

Berke, P., Backhurst, M., Laurian, L., Day, M., Crawford, J., Ericksen, N., & Dixon, J. (2006). What makes plan implementation successful? An evaluation of local plans and implementation practices in New Zealand. *Environment and Planning B: Planning and Design, 33*(4), 581-600.

Berke, P., & Godschalk, D. (2009). Searching for the good plan: A meta-analysis of plan quality studies. *Journal of Planning Literature, 2*(3), 227–240.

Berke, P., Smith, G., & Lyles, W. (2012). Planning for resiliency: Evaluation of state hazard mitigation plans under the Disaster Mitigation Act. *Natural Hazards Review, 13*(2), 139-149.

Berke, P., Spurlock, D., Hess, G., & Band, L. (2013). Local comprehensive plan quality and regional ecosystem protection: The case of the Jordan Lake watershed, North Carolina, U.S.A. *Land Use Policy, 31,* 450-459.

Beyer, H. L. (2010). Geospatial modelling environment. Version 0.5.2. Beta, Edmonton, Alberta.

Blanco-Canqui, H., Gantzer, C. J., Anderson, S. H., Alberts, E. E., & Ghidey, F. (2002). Saturated hydraulic conductivity and its impact on simulated runoff for claypan soils. *Soil Science Society of America Journal*, *66*(5), 1596-1602.

Booth, D. B., & Jackson, C. R. (1997). Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. *Journal of the American Water Resources Association*, *33*(5), 1077-1090. doi: 10.1111/j.1752-1688.1997.tb04126.x.

Boyce, D. (1970). Toward a framework for defining and applying urban indicators in plan-making. *Urban Affairs Quarterly, 6*, 401-415.

Brabec, E. A. (2009). Imperviousness and land-use policy: Toward an effective approach to watershed planning. *Journal of Hydrologic Engineering, 14*(4), 425-433.

Braden, J., & Johnston, D. (2004). Downstream economic benefits from storm-water management. *Journal of Water Resources Planning and Management, 130*(6), 498-505.

Brody, S. D. (2001). A model for ecosystem management through land-use planning: Implementing the principles of ecosystem management in Florida. (Ph.D). Department of City and Regional Planning, The University of North Carolina at Chapel Hill, Chapel Hill, NC.

Brody, S. D. (2003a). Are we learning to make better plans? A longitudinal analysis of plan quality associated with natural hazards. *Journal of Planning Education and Research, 23*(2), 191-201.

Brody, S. D. (2003b). Examining the role of resource-based industries in ecosystem approaches to management: An evaluation of comprehensive plans in Florida. *Society and Natural Resources, 16*(7), 625-641.

Brody, S. D. (2003c). Implementing the principles of ecosystem management through local land use planning. *Population and Environment, 24*(6), 511-540.

Brody, S. D., Highfield, W., & Carrasco, V. (2004). Measuring the collective planning capabilities of local jurisdictions to manage ecological systems in southern Florida. *Landscape and Urban Planning, 69*(1), 33-50.

Brody, S. D., & Highfield, W. (2005). Does planning work?: Testing the implementation of local environmental planning in Florida. *Journal of the American Planning Association, 71*(2), 159-175.

Brody, S. D., Carrasco, V. & Highfield, W. (2006). Measuring the adoption of local sprawl: Reduction planning policies in Florida. *Journal of Planning Education and Research*, *25*(3), 294-310.

Brody, S. D., Highfield, W., Ryu, H.-C., & Spanel-Weber, L. (2007). Examining the relationship between wetland alteration and watershed flooding in Texas and Florida. *Natural Hazards, 40*(2), 413-428.

Brody, S. D. (2008). *Ecosystem planning in Florida: Solving regional problems through local decision-making*. Burlington, VT: Ashgate Publishing Company.

Brody, S., Zahran, S., Highfield, W., Grover, H., & Vedlitz, A. (2008). Identifying the impact of the built environment on flood damage in Texas. *Disasters, 32*(1), 1-18.

Brody, S. D., Kang, J., & Bernhardt, S. (2010). Identifying factors influencing flood mitigation at the local level in Texas and Florida: The role of organizational capacity. *Natural Hazards, 52*(1), 167-184. doi: 10.1007/s11069-009-9364-5.

Brody, S. D., Gunn, J., Peacock, W., & Highfield, W. (2011). Examining the influence of development patterns on flood damages along the Gulf of Mexico. *Journal of Planning Education and Research, 31*(4), 438-448.

Brody, S. D. (2013). The characteristics, causes, and consequences of sprawling development patterns in the United States. *The Nature Education Knowledge Project*, *4*(5), 2.

Brody, S., & Gunn, J. (2013). Examining environmental factors contributing to resilience. In Kapucu, N., Hawkins, C., & Rivera, F, *Disaster resiliency: Interdisciplinary perspectives*. Routledge. Taylor & Francis Group.

Brody, S., & Highfield, W. (2013). Open space protection and flood mitigation: A national study. *Land Use Policy, 32*, 89-95.

Brody, S. D., Kim, H., & Gunn, J. (2013). Examining the impacts of development patterns on flooding on the Gulf of Mexico coast. *Urban Studies, 50*(4), 789-806.

Brown, R., Ryan, R., & McManus, R. (2001). An Australian case study: Why a transdisciplinary framework is essential for integrated urban stormwater planning. P. 251-259. In *Proceedings of frontiers in urban water management,* Marseilles, France. 18–29 June 2001, IHP-V, Technical documents in hydrology, no. 45, UNESCO, Paris.

Brown, R. R. (2005). Impediments to integrated urban stormwater management: The need for institutional reform. *Environmental Management*, *36*(3), 455-468. doi: 10.1007/s00267-004-0217-4.

Brown, R. R., Keath, N., & Wong, T. H. F. (2009). Urban water management in cities: historical, current and future regimes. *Water Science and Technology: A Journal of the International Association on Water Pollution Research, 59*(5), 847-855. doi: 10.2166/wst.2009.029.

Burby, R. J., Bollens, S., Holway, J., Kaiser, E. J., Mullan, D., & Schaffer, J. (1988). *Cities under water: A comparative evaluation of ten cities' efforts to manage floodplain land use*. Boulder, CO: Institute of Behavioral Science, University of Colorado.

Burby, R. J., & Dalton, L. C. (1994). Plans can matter! The role of land use plans and state planning mandates in limiting the development of hazardous areas. *Public Administration Review, 54*(3), 229-238.

Burby, R. J., & May, P. (1997). *Making governments plan: State experiments in managing land use*. Baltimore, MD: Johns Hopkins University Press.

Burby, R. J., Deyle, R., Godschalk, D., & Olshansky, R. (2000). Creating hazard resilient communities through land-use planning. *Natural Hazards Review, 1*(2), 99-106.

Burby, R. J. (2003). Making plans that matter: Citizen involvement and government action. *Journal of the American Planning Association, 69*(1), 33-49.

Burby, R. J. (2005). Have state comprehensive planning mandates reduced insured losses from natural disasters? *Natural Hazards Review, 6*(2), 67-81.

Cahill, T. H. (2012). *Low impact development and sustainable stormwater management.* Hoboken, New Jersey: John Wiley & Sons.

California Stormwater Quality Association (CSQA). (2003). S*tormwater BMP handbook – New development and redevelopment.* Retrieved Jan. 7, 2014, from http://www.cabmphandbooks.com/documents/Development/DevelopmentHandbook.pdf

Campbell, S. (1996). Green cities, growing cities, just cities?: Urban planning and the contradictions of sustainable development. *Journal of the American Planning Association, 62*(3), 296-312.

Campbell, N., D'arcy, B., Frost, C., Novotny, V., & Sansom, A. (2004). *Diffuse pollution: An introduction to the problems and solutions*. London: IWA Publishing.

Cettner, A., Ashley, R., Viklander, M., & Nilsson, K. (2012). Stormwater management and urban planning: Lessons from 40 years of innovation. *Journal of Environmental Planning and Management, 56*(6), 786-801. doi: 10.1080/09640568.2012.706216.

Cettner, A., Ashley, R., Hedstrom, A., & Viklander, M. (2014). Sustainable development and urban stormwater practice. *Urban Water Journal, 11*(3), 185-197.

Chang, H., & Franczyk, J. (2008). Climate change, land-use change, and floods: Toward an integrated assessment. *Geography Compass, 2*(5), 1549-1579. doi: 10.1111/j.1749-8198.2008.00136.x.

Cheng, C., Brabec, E., Yang, Y., & Ryan, R. (2013). Rethinking stormwater management in a changing world: Effects of detention for flooding hazard mitigation under climate change scenarios in the Charles River Watershed. *2013 CELA Landscape Research Record, 1*, 214-228.

Chesapeake Bay Foundation (CBF). (2012). *2012 State of the Bay report*. Retrieved April 23, 2015, from http://www.cbf.org/about-the-bay/state-of-the-bay/2012-report

Chesapeake Bay Foundation (CBF). (2014). P*olluted runoff: How investing in runoff pollution control systems improves the Chesapeake Bay region's ecology, economy, and health*. Retrieved June 3, 2014, from http://www.cbf.org/features-publications/reports/polluted-runoff-report-2014

Chesapeake Bay Program. (2000). *Chesapeake 2000*. Retrieved April 23, 2015, from http://www.chesapeakebay.net/content/publications/cbp_12081.pdf

Coffman, L. S., Goo, R., & Frederick, R. (1999). Low impact development an innovative alternative approach to stormwater management. In *Proceedings of the 26th Annual Water Resources Planning and Management Conference* ASCE, June 6-9, Temple, Arizona.

Conroy, M., & Berke, P. (2004). What makes a good sustainable development plan? An analysis of factors that influence principles of sustainable development. *Environmental and Planning A*, *36*(8), 1381-1396.

Cook, T., & Campbell, D. (1979). *Quasi-experimentation: Design and analysis issues for field settings*. Boston, MA: Houghton Mifflin Company.

Dalton, L., & Burby, R. (1994). Mandates, plans and planners: Building local commitment to development management. *Journal of the American Planning Association, 60*(4), 444-461.

Davis, B. C. (2004). Regional planning in the US coastal zone: A comparative analysis of 15 special area plans. *Ocean and Coastal Management, 47*(1-2), 79-94.

Debo, T., & Reese, A. (2003). *Municipal stormwater management*. (2nd ed.). CRC Press LLC: Boca Raton, FL.

Demissie M., Khan, A. & al-Mubarak, R. (1991). Influence of wetlands on streamflow in Illinois. In *Proceedings of the ASCE National Conference on Hydraulic Engineering*. Nashville, TN: ASCE.

Department of the Environment and Heritage (DEH). (2002). *Introduction to urban stormwater management in Australia*. Retrieved Nov. 15, 2013, from http://www.environment.gov.au/resource/introduction-urban-stormwater-management-australia

Department of Environment and Heritage Protection (DEHP). (2010). *Urban stormwater quality planning guidelines*. The State of Queensland, Australia. Retrieved Dec. 14, 2013, from www.ehp.qld.gov.au/water/policy/pdf/urban-water-web.pdf

Deyle, R. E., & Smith, R. A. (1998). Local government compliance with state plan mandates: The effects of state implementation in Florida. *Journal of the American Planning Association, 64*(4), 457-69.

Deyle, R. E., Chapin, T. S., & Baker, E. J. (2008). The proof of the planning is in the platting: An evaluation of Florida's hurricane exposure mitigation planning mandate. *Journal of the American Planning Association, 74*(3), 349-370.

Dollery, B., & Marshall, N. (1997). *Australian local government: Reform and renewal*. South Melbourne, Victoria: Macmillan Education Australia Pty Ltd.

Dunn, T., & Leopold, L. (1978). *Water in Environmental Planning*. San Francisco, CA: W.H. Freeman and Company.

Edwards, M., & Haines, A. (2007). Evaluating smart growth: Implications for small communities. *Journal of Planning Education and Research, 27*(1), 49-64.

Evans-Cowley, J. S., & Gough, M. G. (2008). Evaluating environmental protection in post-hurricane Katrina plans in Mississippi. *Journal of Environmental Planning and Management, 51*(3), 399-319.

Evans-Cowley, J. S., & Gough, M. G. (2009). Evaluating new urbanist plans in post-Katrina Mississippi. *Journal of Urban Design, 14*(4), 439-461.

Evenson, K. R., Satinsky, S. B., Rodriguez, D. A., & Aytur, S. A. (2012). Exploring a public health perspective on pedestrian planning. *Health Promotion Practice, 13*(2), 204-213.

Fishman, R. (1978). The state of art in local planning. In R. Fishman (Ed.), *Housing for all under law*. (pp.5-10). Cambridge, MA: Ballinger.

Forester, J. (1984). Bounded rationality and the politics of muddling through. *Public Administration Review, 44*(1), 23–31.

Frederick, K., & Major, D. (1997). Climate change and water resources. *Climatic Change, 37*(1), 7-23.

Freelon, D. (2010). ReCal: Intercoder reliability calculation as a web service. *International Journal of Internet Science, 5*(1), 20-33.

Fu, X., & Tang, Z. (2013). Planning for drought-resilient communities: An evaluation of local comprehensive plans in the fastest growing counties in the US. *Cities, 32*, 60-69.

Gaffney, M. (1964). Containment policies for urban sprawl. In R. L. Stabuber (Eds.), *Approaches to the study of urbanization*. Lawrence: University of Kansas.

Gearheart, G. (2007). A review of low impact development policies: Removing institutional barriers to adoption. Low Impact Development Center. December 2007, Beltsville, Maryland.

Godschalk, D., Brower, D., & Beatley, T. (1989). *Catastrophic coastal storms: Hazard mitigation and development management*. Durham, NC: Duke University Press.

Godschalk, D., Beatley, T., Berke, P., Brower, D., & Kaiser, E. (1999). *Natural Hazard Mitigation*. Washington, DC: Island Press.

Hamin, E. M. (2011). Integrating adaptation and mitigation in local climate change planning. In G. K. Ingram, & Y.-H. Hong (eds.), *Climate change and land policies*. Cambridge: Lincoln Institute of Land Policy.

Heinze, J. (2011). *Benefits of green space – Recent research*. Environmental Health Research Foundation. Retrieved Jan. 3, 2014, from http://www.kisssusa.com/library/docs/links/BenefitsofGreenSpace-1.pdf

Highfield, W. (2008). *Section 404 permitting in coastal Texas from 1996-2003: Patterns and effects on streamflow*. (Ph.D.), Urban and Regional Sciences. Texas A&M University, College Station, TX.

Highfield, W. (2012). Section 404 permitting in coastal Texas: A longitudinal analysis of the relationship between peak streamflow and wetland alteration. *Environmental Management, 49*(4), 892-901.

Highfield, W., & Brody, S. (2013). Evaluating the effectiveness of local mitigation activities in reducing flood losses. *Natural Hazards Review, 14*(4), 229-236.

Hirsch, R., Walker, J., Day, J., & Kallio, R. (1990). The influence of main on hydrological systems. In *Surface water hydrology*, vol. 0-1, ed. MG Wolman, and HC Riggs. Boulder, CO: Geological Society of America, 329-59.

Hoch, C. (2007). How plan mandates work: Affordable housing in Illinois. *Journal of the American Planning Association, 73*(1), 86–99.

Hollis, G. (1975). Effect of urbanization on floods of different recurrence interval. *Water Resources Research, 1975*(11), 431-435.

Homer, C. C., Yang, H. L., Wylie, B., & Coan, M. (2004). Development of a 2001 national landcover database for the United States. *Photogrammetric Engineering and Remote Sensing, 70*(7), 829-840.

Horney, J. A., Naimi, A. I., Lyles, W., Simon, M., Salvesen, D., & Berke, P. (2012). Assessing the relationship between hazard mitigation plan quality and rural status in a cohort of 57 counties from 3 states in the southeastern U.S. *Challenges, 3*(2), 183-193.

Horton, R. E. (1932). Drainage basin characteristics. *Transactions of the American Geophysical Union, 13*, 350–361.

Hosseinzadeh, S. (2005). The effects of urbanization on the natural drainage patterns and the increase of urban floods: Case study Metropolis of Mashhad-Iran. *Sustainable Development and Planning II, 1-2*(84), 423-432.

Huber, J. (2010). *Low impact development: A design manual for urban areas*. Arkansas: University of Arkansas Community Design, University of Arkansas Press.

Indiana University Dictionary. (2013). *Internal validity*. Retrieved Feb. 1, 2014, from www.indiana.edu/~p1013447/dictionary/int_val.htm

Institute for Business and Home Safety. (2010). Maps from the Summary of State Land Use Planning Laws. Retrieved Feb. 2, 2015, from https://ofb.ibhs.org/content/data/file/maps.pdf

IPCC. (2007). Climate change 2007: The IPCC fourth assessment report. UNEP.

Kaiser, E. J., & Burby, R. J. (1987). Emerging state roles in urban stormwater management. *American Water Resources Bulletin, 23*(3), 443-453. doi: 10.1111/j.1752-1688.1987.tb00822.x.

Kaiser, E. J., Godschalk, D., & Chapin, F. (1995). *Urban land use planning*. (4th ed.). University of Illinois Press.

Kang, J. E. (2009). Mitigating flood loss through local comprehensive planning in Florida. (Ph.D.), Urban and Regional Science, Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, TX.

Kang, J. E., Peacock, W. G., & Husein, R. (2010). An assessment of coastal zone hazard mitigation plans in Texas. *Journal of Disaster Research. 5*(5), 520–28.

Kaplowitz, M.D., & Lupi, F. (2012). Stakeholder preferences for best management practices: A choice experiment in Mid-Michigan's Sycamore Creek. *Landscape and Urban Planning, 104*(3–4), 364-372.

Kent, T., & Jones, H. (1990). *The urban general plan*. Chicago, IL: American Planning Association.

Kloss, C., & Calarusse, C. (2006). *Rooftops to rivers: Green strategies for controlling stormwater and combined sewer overflows*. Washington, DC: Natural Resources Defense Council.

Krippendorff, K. (2013). *Content analysis: An introduction to its methodology*. (3rd ed.). Thousand Oaks, CA: Sage Publications.

Laurian, L., Day, M., Berke, P., Ericksen, N., Backhurst, M., Crawford, J., & Dixon, J. (2004). Evaluating plan implementation: A conformance-based methodology. *Journal of American Planning Association, 70*(4), 471-480.

Laurian, L., Crawford, J., Day, M., Kouwenhoven, P., Mason, G., Ericksen, N., & Beattie, L. (2010). Evaluating the outcomes of plans: Theory, practice, and methodology. *Environment and Planning B: Planning and Design, 37*, 740-757.

Lawrence, D. P. (2000). Planning theories and environmental impact assessment. *Environmental Impact Assessment Review, 20*(6), 607–625.

Lehner, P. H., Aponte Clarke, G. P., Cameron, D. M., & Frank, A. G. (1999). *Stormwater strategies: Community responses to runoff pollution*. New York: Natural Resources Defense Council.

Lindh, J. (2013). Sustainable stormwater management to address pollution and climate change. (M.S.), Department of Biological and Environmental Sciences, Goteborgs University. Sweden.

Lyles, W., & Stevens, M. (2014). Plan quality evaluation 1994–2012: Growth and contributions, limitations, and new directions. *Journal of Planning Education and Research, 34*(4), 433-450.

Maclaren, V. (1996). Urban sustainability reporting. *Journal of the American Planning Association, 62*, 184–202.

Matthai, H.F. (1990). Floods. In M. G. Wolman, & H. C. Riggs. (Eds.), *The geology of North America Vol. 0-1, Surface water hydrology* (pp. 97-120). The Geologic Society of America: Boulder, CO.

Maxwell, J. A. (1996). *Qualitative research design: An interactive approach*. Thousand Oaks, CA: Sage Publications.

McDonald, L., Allen, W., Benedict, M., & O'Connor, K. (2005). Green infrastructure plan evaluation frameworks. *Journal of Conservation Planning, 1*(1), 12-43.

McManus, R., & Brown, R. (2002). The increasing organizational uptake of source control approaches for sustainable stormwater management. In *Proceedings of* *the Ninth International Conference on Urban Drainage*, 8-13, September, 2002. Portland, Oregon.

Mega, V. (1996). Our city, our future: Towards sustainable development in European cities. *Environment and Urbanization, 8*(1), 133–154.

Merriam-Webster.com. (2013). Sustain. Retrieved Sep. 17, 2013, from http://www.merriam-webster.com/dictionary/sustain

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded Sourcebook.* (2nd ed.). Sage Publications, Inc.

Morison, P. J. (2009). Management of urban stormwater: Advancing program design and evaluation. (Ph.D.), School of Geography and Environmental Science. Monash University.

Mount, J. F. (1995). *California rivers and streams: The conflict between fluvial process and land use.* University of California Press.

National Commission on the Environment (NCE). (1993). *Choosing a sustainable future*. Washington, DC: Island Press.

National Research Council (NRC). (2008). *Urban stormwater management in the United States*. Washington, DC: The National Academies Press.

Natural Resources Conservation Service (NRCS). (1998). Disturbance affecting stream corridors. In *Federal stream corridor restoration handbook.* USDA Natural Resources Conservation Service. Retrieved Dec. 30, 2013, from www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044610.pdf

Natural Resources Conservation Service (NRCS). (2008). *SSURGO soils – Permeability all layers*. Retrieved Dec. 12, 2013, from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_028516.pdf

Natural Resources Defense Council (NRDC). (2011). *After the storm: How green infrastructure can effectively manage stormwater runoff from roads and highways*. Natural Resources Defense Council Retrieved Nov. 11, 2013, from http://www.nrdc.org/water/afterthestorm.asp

Nelson, A., & French, S. (2002). Plan quality and mitigating damage from natural disasters: A case study of the Northridge earthquake with planning policy considerations. *Journal of the American Planning Association, 68*(2), 194-207.

Neuman, M. (1999). *The sustainability question: Beyond the compact city fallacy: Planning sustainable urban development.* Berkeley, CA: The Michael Neuman Consultancy.

New York State Department of Environmental Conservation (NYSDEC). (2014). *Chesapeake Bay watershed program*. Retrieved Jan. 21, 2014 from http://www.dec.ny.gov/lands/33279.html

Niemczynowicz, J. (1999). Urban hydrology and water management - present and future challenges. *Urban Water, 1*(1), 1–14.

Norton, R. (2005). More and better local planning: State-mandated local planning in coastal North Carolina. *Journal of the American Planning Association, 71*(1), 55-71.

Norton, R. (2008). Using content analysis to evaluate local master plans and zoning codes. *Land Use Policy, 25*(3), 432-454.

Novitski, R. (1985). The effects of lakes and wetlands on flood flows and base flows in selected northern and eastern states. In *Proceedings of the Conference on Wetlands of the Chesapeake*. Easton, MD: Environmental Law Institute.

Nunnally, J. C. (1978). *Psychometric Theory*. (2nd ed.). New York: McGraw-Hill.

Office of Facilities, Utilities & Engineering (OFUE). (2013). Yale University sustainable stormwater management plan. Retrieved Nov. 29, 2013, from http://sustainability.yale.edu/news/yale-announces-stormwater-management-plan

Olonilua, O. O., & Ibitayo, O. O. (2011). Toward multihazard mitigation: An evaluation of FEMA approved hazard mitigation plans under the Disaster Mitigation Act of 2000. *Journal of Emergency Management, 9*(1), 37-49.

Olshansky, R. (2001). Comprehensive land use planning for seismic safety: The Los Angeles county experience, 1971-1994. *Journal of the American Planning Association, 67*(2), 173-185.

Parkinson, J., & Mark, O. (2005). *Urban stormwater management in developing countries*. London: IWA Publishing.

Paul, M., & Meyer, J. (2001). Streams in the urban landscape. *Annual Review of Ecological Systems, 32*, 333–365.

Pedhazur, E., & Schmelkin, L. (1991). *Measurement, design, and analysis: An integrated approach*. Lawrence Erlbaum Associates.

Perez-Pedini, C., Limbrunner, J., & Vogel, R. (2005). Optimal location of infiltration-based best management practices for storm water management. *Journal of Water Resources Planning and Management*, *131*(6), 441-448.

Phillips, S. W. (2006). *U.S. geological survey Chesapeake Bay studies: Scientific solutions for a healthy bay and watershed*. USGS Fact Sheet FS 2006-3046. Retrieved May 11, 2015, from http://pubs.usgs.gov/fs/2006/3046

Pitt, R., & Clark, S. (2008). Integrated storm-water management for watershed sustainability. *Journal of Irrigation and Drainage Engineering, 134*(5), 548-555.

Prince George's County. (1999). Low-impact development design strategies: An integrated design approach. Prince George's County, Department of Environmental Resources, Programs and Planning Division. Retrieved July 9, 2013, from http://www.ebah.com.br/content/ABAAAgOHQAJ/low-impact-development-design-strategies-an-integrated-design-approach

Pyzoha, D. (1994). *Implementing a stormwater management program*. Florida: CRC Press, Inc.

Randolph, J. (2004). *Environmental land use planning and management*. Washington DC: Island Press.

Rice, K. C., & Hirsch, R. M. (2012). Spatial and temporal trends in runoff at long-term streamgages within and near the Chesapeake Bay Watershed. U.S. Geological Survey Scientific Investigations Report 2012–5151, p. 56. Retrieved Dec. 11, 2013 from http://pubs.usgs.gov/sir/2012/5151

Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., Brown, R. R. (2008). Impediments and solutions to sustainable, watershed-scale urban stormwater management: Lessons from Australia and the United States. *Environmental Management, 42*(2), 344-359.

Running, S.W., & Thornton, P.E. (1996). Generating daily surfaces of temperature and precipitation over complex topography. In M.F. Goodchild, L.T. Steyaert, B. O. Parks, M. P. Crane, C. A. Johnston, D. A. Maidment, & S. Glendinning (Eds.), *GIS and environmental modeling, progress and research issues*. (pp. 93-98). Ft. Collins: GIS World Inc..

Sala, M. (2003). Floods triggered by natural conditions and by human activities in a Mediterranean coastal environment. Geografiska Annaler. Series A, *Physical Geography, 85*(3/4), 301-312.

Schueler, T. (1994). The importance of imperviousness. *Watershed Protection Techniques, 1*(3), 100-111.

Shuster, W., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D. (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal, 2*(4), 263-275.

Scott, D., & Willits, F. K. (1994). Environmental attitudes and behavior. *Environmental Behavior, 26*(2), 239-261.

Shadish, W., Cook, T., & Campbell, D. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Boston, MA: Houghton Mifflin.

Sharpin (1998). *Managing urban stormwater: Source control*. (December 1998). New South Wales Environment Protection Authority, Chatswood, Australia. Retrieved Oct. 3, 2013, from http://www.epa.nsw.gov.au/stormwater/download/srcectrl.pdf

Shaver, E., Horma, R., Skupien, J., May, C., & Ridley, G. (2007). *Fundamentals of urban runoff management: Technical and institutional issues.* (2nd ed.). Produced in Cooperation with USEPA. Madison, WI. North American Lake Management Society.

Shepard, A., & Ortolano, L. (1996). Strategic environmental assessment for sustainable development. *Environmental Impact Assessment Review, 16*, 321–335.

Society of Soil Scientists of Northern New England (SSSNNE). (2009). Ksat values for New Hampshire soils. SSSNNE Special Publication No. 5. Retrieved May 3, 2015, from https://sssnne.files.wordpress.com/2013/03/ksatnh.pdf

Spinner, C. (2002). *An integrated approach to stormwater management in the coastal zone*. (M.S.), The School of Landscape Architecture. Louisiana State University.

Srivastava, R., & Laurian, L. (2006). Natural hazard mitigation in local comprehensive plans: The case of flood, wildfire and drought planning in Arizona. *Disaster Prevention and Management, 15*(3), 461-483.

Stahre, P. (2002). Integrated planning of sustainable stormwater management in the City of Malmo, Sweden. In *Proceedings of Global Solutions for Urban Drainage*, 1-14.

Stahre, P., & Geldof, G. D. (2003). *New approach to sustainable stormwater planning*. Retrieved Jan. 7, 2014, from http://www.greenroof.se

Steelman, T. A., & Hess, G. R. (2009). Effective protection of open space: Does planning matter? *Environmental Management, 44*, 93-104.

Stevens, M., Berke, P., & Song, Y. (2010). Creating disaster-resilient communities: Evaluating the promise and performance of new urbanism. *Landscape and Urban Planning, 94*(2), 105-115.

Stevens, M. (2013). Evaluating the quality of official community plans in southern British Columbia. *Journal of Planning Education and Research, 33*(4), 417-490.

Stevens, M., Lyles, W., & Berke, P. (2014). Measuring and reporting intercoder reliability in plan quality evaluation research. *Journal of Planning Education and Research, 34*(1), 77-93.

Stone, B., Vargo, J., & Habeeb, D. (2012). Managing climate change in cities: Will climate action plans work? *Landscape and Urban Planning, 107*(3), 263-71.

Stuckey, M. (2006). *Low-flow, base-flow, and mean-flow regression equations for Pennsylvania stream*. U.S. Geological Survey, Scientific Investigations Report 2006-5130. Washington, DC.

Talen, E. (1996). Do plans get implemented? A review of evaluation in planning. *Journal of Planning Literature, 10*(3), 248-259.

Talen, E., & Knaap, G. (2003). Legalizing smart growth: An empirical study of land use regulation in Illinois. *Journal of Planning Education and Research, 22*, 345-359.

Tang, Z. (2008). Evaluating local coastal zone land use planning capacities in California. *Ocean & Coastal Management, 51*(7), 544-555.

Tang, Z., Lindell, M., Prater, C., & Brody, S. (2008). Measuring tsunami planning capacity on U.S. Pacific coast. *Natural Hazards Review, 9*(2), 91-100.

Tang, Z., & Brody, S. (2009). Link planning theories with factors influencing local environmental plan quality, environment and planning. *Planning and Design, 36*(3), 522-537.

Tang, Z., Brody, S., Quinn, C., Chang, L., & Wei, T. (2010). Moving from agenda to action: Evaluating local climate change action plans. *Journal of Environmental Planning and Management, 53*(1), 41-62.

Tang, Z, Brody, S., Li, R., Quinn, C., & Zhao, N. (2011) Examining locally driven climate change policy efforts in three Pacific states. *Ocean and Coastal Management, 54*(5), 415-426.

Termorshuizen, J. W., Opdam, P., & van den Brink, A. (2007). Incorporating ecological sustainability into landscape planning. *Landscape and Urban Planning, 79*(3-4), 374-84.

Texas Commission on Environmental Quality (TCEQ). (2010). *Preserving and improving water quality*. Retrieved Jan. 17, 2013, from http://www.tceq.texas.gov/publications/gi/gi-351.html

The National Academies. (2009). *Urban stormwater management in the United States*. Washington, DC: The National Academies Press.

Tyrväinen, L., Pauleit, S., Seeland, K., & de Vries, S. (2005). Benefits and uses of urban forests and trees. In *Urban forests and trees* (pp. 81-114). Berlin Heidelberg: Springer.

Urban Land Institute, American Society of Civil Engineers, and National Association of Home Builders. (1975). Residential storm water management: Objectives, principles and design considerations. Washington, DC and New York, New York.

U.S. Environmental Protection Agency (USEPA). (1983). *Results of the nationwide urban runoff program: Volume 1 - Final report*. Retrieved Jan. 4, 2014, from http://yosemite.epa.gov/water/owrccatalog.nsf/065ca07e299b464685256ce50075c11a/62b29cd72280166085256b0600724ce9!OpenDocument

U.S. Environmental Protection Agency (USEPA). (1988). *Design manual: Constructed wetlands and aquatic plant systems for municipal wastewater treatment*. Cincinnati, Ohio: U.S. Environmental Protection Agency Office of Research and Development.

U.S. Environmental Protection Agency (USEPA). (1992). *Environmental impacts of stormwater discharges: A national profile*. Retrieved Dec. 20, 2013, from http://yosemite.epa.gov/water/owrcCatalog.nsf/065ca07e299b464685256ce50075c11a/dc0576540618139d85256b0600723790!OpenDocument

U.S. Environmental Protection Agency (USEPA). (2004). *Report to congress: Impacts and control of CSOs and SSOs*. (EPA-833-R-04-001). Retrieved Dec. 8, 2013, from http://cfpub.epa.gov/npdes/cso/cpolicy_report2004.cfm

U.S. Environmental Protection Agency (USEPA). (2005). *National management measures to control nonpoint source pollution from urban areas*. (EPA-841-B-

05-004). Retrieved Jan. 20, 2014, from http://www.epa.gov/owow/nps/urbanmm/index.html

U.S. Environmental Protection Agency (USEPA). (2007). *Reducing stormwater costs through low impact development strategies and practices*. December 2007. (EPA 841-F-07-006). Prepared under Contract No. 68-C-02-108. Washington, DC. Retrieved Mar. 19, 2015, from http://water.epa.gov/polwaste/green/upload/2008_01_02_NPS_lid_costs07uments_reducingstormwatercosts-2.pdf

U.S. Environmental Protection Agency (USEPA). (2008). *Chesapeake Bay health and restoration assessment - A report to the citizens of the Bay region*. (EPA-903-R-08-002). Annapolis, MD: U. S. Environmental Protection Agency. Retrieved Aug. 3, 2014, from http://www.chesapeakebay.net/documents/cbp_26038.pdf

U.S. Environmental Protection Agency (USEPA). (2009). *Technical guidance on implementing the stormwater runoff requirements for federal projects under Section 438 of EISA*. Retrieved Dec. 10, 2013, from http://www.epa.gov/oaintrnt/documents/epa_swm_guidance.pdf

U.S. Environmental Protection Agency (USEPA). (2010). *Combined sewer overflows: Overview*. Retrieved Oct. 20, 2013, from http://cfpub.epa.gov/npdes/home.cfm?program_id=5

U.S. Environmental Protection Agency (USEPA). (2012). *A handbook for water and wastewater utilities*. February, 2012. (EPA-832-R-12-001). Retrieved Dec. 2, 2013, from http://water.epa.gov/infrastructure/sustain/upload/EPA-s-Planning-for-Sustainability-Handbook.pdf

U.S. Environmental Protection Agency (USEPA). (2013). *Impaired water and total maximum daily loads*. Retrieved Jan. 28, 2014, from http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl

U.S. Green Building Council. (USGBC). (2013). *LEED for neighborhood development v2009*. Retrieved Dec. 20, 2013, from http://www.usgbc.org/resources/leed-neighborhood-development-v2009-current-version

Visitacion, B. J., Booth, D. B., & Steinemann, A. C. (2009). Costs and benefits of storm-water management: Case study of the Puget Sound region. *Journal of Urban Planning and Development*, *135*(4), 150-158.

Wardrop, D. H., Bishop, J. A., Easterling, M., Hychka, K., Myers, W., Patil, G. P., & Taillie, C. (2005). Use of landscape and land use parameters for classification and characterization of watersheds in the mid-Atlantic across five physiographic provinces. *Environmental and Ecological Statistics, 12*(2), 209-223.

Water Environment Research Foundation (WERF). (2010). *Commonly used policies and programs*. Retrieved Jan. 6, 2014, from http://www.werf.org/liveablecommunities/toolbox/policies.htm

Weber, T., Sloan, A., & Wolf, J. (2006). Maryland’s green infrastructure assessment: Development of a comprehensive approach to land conservation. *Landscape and Urban Planning*, *77*(1-2), 94-110.

Wheeler, S. M. (2008). State and municipal climate change plans. *Journal of the American Planning Association, 74*(4), 481–96.

Wong, T. H. F. (2001). A changing paradigm in Australian urban stormwater management. In *proceedings of the 2nd South Pacific Stormwater Conference*, 27-29, June 2001, Auckland, New Zealand.

Wooldridge, J. (2009). *Introductory econometrics: A modern approach*, (4th ed.). Mason Ohio: Thomson: South-Western.

World Commission on Environment and Development (WCED). (1987). *Our common future*. Oxford, England: Oxford University Press.

Wright, J. M. (2008). Floodplain management: Principles and current practices. *The University of Tennessee–Knoxville. On-Line Address: http://training.fema.gov/EMIWeb/edu/fmpcp.asp*

Yang, B., & Li, M-H. (2011). Assessing planning approaches by watershed streamflow modeling: Case study of The Woodlands; Texas. *Landscape and Urban Planning, 99*(1), 9-22.

Yang, X., You, X., Ji, M., & Nima, C. (2013). Influence factors and prediction of stormwater runoff of urban green space in Tianjin, China: Laboratory experiment and quantitative theory model. *Water Science & Technology, 67*(4), 869-876.

Youngquist, T. D. (2009). *What is green infrastructure? An evaluation of green infrastructure plans from across the United States.* (M.S.). Community and Regional Planning, Iowa State University, Ames, IA.

Zomorodi, K. (2004). *Curve number and groundwater recharge credits for LID facilities in New Jersey*. Retrieved April 8, 2013, from http://www.industrycortex.com/datasheets/profile/1003766606 curve-number-and-groundwater-recharge-credits-for-lid-facilities

APPENDIX A

Correlation Matrix

	Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	Plan quality	1.000									
2	Plan year	0.563*	1.000								
3	Number of planners	0.320*	0.195	1.000							
4	Consultant	0.012	0.156	-0.138	1.000						
5	Population density	0.034	-0.016	0.236*	-0.175	1.000					
6	Wealth	0.377*	0.234*	0.428*	-0.162	0.022	1.000				
7	Education	0.303*	0.041	0.439*	-0.197	-0.014	0.630*	1.000			
8	Property damage (log)	0.055	0.055	0.164	0.257*	0.149	-0.131	0.181	1.000		
9	Storm event	-0.231*	-0.07	0.119	0.057	0.186	-0.151	0.043	0.430*	1.000	
10	Impervious surface	0.227*	0.008	0.393*	-0.136	0.798*	0.235	0.222	0.250*	0.112	1.000

Note: *: significant at p<.05

APPENDIX B

Total Plan Quality Scores by Local Jurisdiction

States	Local jurisdictions	Factual basis	Goals and objectives	Inter-organization-al coordination	Policies, tools, and strategies	Impleme-ntation	Total plan score
MD	Allegany	3.61	4.55	5.00	3.28	1.67	**18.10**
	Anne Arundel	6.67	5.45	7.86	4.83	8.33	**33.14**
	Baltimore City	3.89	3.64	4.29	1.72	5.00	**18.54**
	Baltimore	6.11	8.18	5.71	4.31	5.83	**30.15**
	Calvert	5.00	7.27	7.86	4.48	5.00	**29.61**
	Caroline	6.11	5.45	4.29	2.41	3.33	**21.60**
	Carroll	7.22	4.55	7.86	3.45	5.00	**28.07**
	Cecil	6.39	5.45	7.14	3.62	7.50	**30.11**
	Charles	4.17	6.36	5.71	2.24	5.00	**23.49**
	Frederick	6.67	4.55	7.86	3.45	2.50	**25.02**
	Harford	2.78	4.55	6.43	1.55	5.83	**21.14**
	Howard	5.83	3.64	7.14	3.45	5.00	**25.06**
	Kent	6.39	3.64	5.00	2.24	1.67	**18.93**
	Prince George's	4.72	4.55	5.71	1.90	2.50	**19.38**
	Queen Anne's	6.11	4.55	3.57	3.97	5.00	**23.19**
	St. Mary's	5.56	6.36	5.71	5.34	5.00	**27.98**
	Talbot	6.11	3.64	5.00	4.14	2.50	**21.39**
	Washington	6.39	3.64	3.57	1.55	0.83	**15.98**
	Wicomico	5.83	8.18	5.71	4.31	2.50	**26.54**
PA	Bedford	6.67	4.55	5.00	3.45	5.83	**25.49**
	Blair	6.11	4.55	7.14	2.76	7.50	**28.06**
	Bradford	4.44	0.91	4.29	1.90	1.67	**13.20**
	Centre	5.83	2.73	4.29	2.24	1.67	**16.75**
	Clearfield	6.67	6.36	5.71	2.07	3.33	**24.15**
	Clinton	4.44	3.64	3.57	0.69	4.17	**16.51**
	Cumberland	6.39	2.73	3.57	1.55	3.33	**17.57**
	Dauphin	6.67	5.45	4.29	2.41	3.33	**22.15**
	Fulton	5.00	1.82	3.57	1.03	2.50	**13.92**
	Huntingdon	6.39	2.73	5.00	2.76	0.83	**17.71**
	Juniata	6.67	4.55	7.14	2.24	5.83	**26.43**
	Lebanon	7.50	5.45	6.43	1.72	5.00	**26.11**
	Lycoming	6.11	4.55	5.71	2.07	3.33	**21.77**
	Mifflin	5.83	3.64	5.71	1.72	5.83	**22.74**
	Montour	3.33	5.45	4.29	2.59	5.83	**21.49**
	Northumberl-and	4.17	2.73	6.43	2.93	3.33	**19.59**
	Perry	6.67	3.64	7.14	3.28	3.33	**24.06**

Table Continued

States	Local jurisdictions	Factual basis	Goals and objectives	Inter-organization-al coordination	Policies, tools, and strategies	Impleme-ntation	Total plan score
PA	Potter	6.11	5.45	5.71	2.41	5.83	**25.53**
	Schuylkill	5.83	3.64	5.00	1.90	5.83	**22.20**
	Snyder	3.89	3.64	5.00	1.55	5.00	**19.08**
	Tioga	6.39	6.36	5.00	2.07	3.33	**23.15**
	Union	3.61	3.64	5.71	2.59	5.00	**20.55**
VA	Alleghany	7.22	4.55	1.43	1.55	0.83	**15.58**
	Amelia	4.72	3.64	1.43	2.93	0.83	**13.55**
	Amherst	3.61	5.45	5.00	2.76	3.33	**20.16**
	Appomattox	3.89	4.55	3.57	2.07	2.50	**16.57**
	Augusta	7.78	6.36	7.14	4.31	7.50	**33.09**
	Botetourt	6.11	2.73	6.43	2.59	1.67	**19.52**
	Buckingham	6.39	4.55	4.29	2.59	1.67	**19.47**
	Culpeper	7.22	6.36	5.71	3.45	3.33	**26.08**
	Cumberland	4.44	2.73	2.86	2.07	0.83	**12.93**
	Fluvanna	7.50	7.27	7.86	4.66	6.67	**33.95**
	Goochland	5.83	7.27	7.14	4.31	5.83	**30.39**
	Greene	4.72	6.36	3.57	2.24	2.50	**19.40**
	Hanover	4.17	4.55	4.29	1.55	2.50	**17.05**
	Henrico	6.67	9.09	6.43	3.79	8.33	**34.31**
	James City	7.22	4.55	5.71	4.31	5.83	**27.63**
	King George	4.72	4.55	4.29	2.41	1.67	**17.63**
	King William	6.39	7.27	6.43	3.10	2.50	**25.69**
	Lancaster	3.61	3.64	5.00	2.59	3.33	**18.17**
	Louisa	5.28	4.55	3.57	2.41	2.50	**18.31**
	Middlesex	5.56	6.36	5.00	2.59	3.33	**22.84**
	Nelson	5.56	3.64	2.14	1.21	0.83	**13.38**
	New Kent	5.28	4.55	3.57	2.93	0.83	**17.16**
	Northumberl-and	7.22	4.55	6.43	3.62	5.83	**27.65**
	Orange	5.83	5.45	3.57	3.28	3.33	**21.47**
	Page	7.22	4.55	6.43	3.79	8.33	**30.32**
	Powhatan	3.89	5.45	4.29	3.28	7.50	**24.41**
	Prince Edward	5.28	3.64	5.00	2.41	2.50	**18.83**
	Prince William	3.61	8.18	3.57	3.79	4.17	**23.32**
	Rockingham	5.00	4.55	4.29	2.07	6.67	**22.57**
	Spotsylvania	5.56	5.45	5.00	5.17	6.67	**27.85**
	Stafford	6.67	4.55	5.71	4.48	6.67	**28.08**
	Westmoreland	7.22	6.36	5.00	3.97	3.33	**25.88**
	York	5.56	7.27	5.00	4.14	5.00	**26.97**
WV	Jefferson	2.22	0.91	2.74	0.86	0.83	**7.56**
DC	Washington DC	4.17	6.36	7.86	3.45	8.33	**30.17**

APPENDIX C

Descriptive Statistics of Dependent Variables by the USGS Gauge

State	County	Gauge station #	Drainage area (km^2)	Annual runoff depth (mm)	
				Mean	Peak
MD	Wicomico	01485500	116.29	0.902	11.995
MD	Wicomico	01486500	50.50	1.228	25.953
MD	Queen Anne's	01491500	220.67	1.368	46.622
MD	Queen Anne's	01492500	20.95	1.491	160.727
MD	Queen Anne's	01493000	51.02	1.338	36.287
MD	Kent	01493112	15.85	1.422	152.962
MD	Kent	01493500	32.89	1.106	138.087
PA	Tioga	01516350	396.27	1.460	45.904
PA	Tioga	01516500	31.60	1.249	99.612
PA	Bradford	01532000	556.85	1.532	110.309
PA	Potter	01544500	352.24	1.782	27.280
PA	Centre	01547200	686.35	1.533	23.179
PA	Centre	01547700	114.22	1.311	39.734
PA	Lycoming	01549500	97.64	1.761	52.174
PA	Lycoming	01550000	448.07	1.951	62.752
PA	Montour	01553700	132.87	1.529	62.331
PA	Bedford	01556000	753.69	1.541	24.143
PA	Huntingdon	01558000	569.80	1.553	25.301
PA	Bedford	01560000	445.48	1.486	39.501
PA	Mifflin	01565000	424.76	1.548	23.832
PA	Perry	01568000	536.13	1.713	53.198
PA	Cumberland	01571500	551.67	1.692	25.645
PA	Schuylkill	01572025	300.44	2.087	62.887
MD	Harford	01581500	22.07	1.808	225.070
MD	Harford	01581649	23.70	1.565	201.805
MD	Harford	01581757	144.00	1.646	114.850
MD	Baltimore	01581920	211.08	1.435	44.681
MD	Baltimore	01582000	137.01	1.511	60.401
MD	Baltimore	01583500	154.88	1.442	104.494
MD	Baltimore	01583600	54.13	1.708	89.491
MD	Baltimore	01584050	24.35	1.354	84.640
MD	Baltimore	01585100	19.71	1.925	409.628
MD	Baltimore	01585104	6.47	1.833	374.451
MD	Baltimore	01585200	5.52	1.537	794.618
MD	Carroll	01586000	146.59	1.385	80.068
MD	Carroll	01586210	36.26	1.403	83.549
MD	Carroll	01586610	72.52	1.304	74.389
MD	Baltimore	01589100	6.40	1.376	411.793
MD	Baltimore	01589300	84.17	1.572	153.175
MD	Baltimore	01589330	14.30	1.954	403.863
MD	Baltimore	01589440	65.27	1.516	200.452

Table Continued

State	County	Gauge Station #	Drainage Area (km^2)	Annual Runoff Depth (mm)	
				Mean	Peak
MD	Anne Arundel	01589500	12.87	1.418	92.230
MD	Anne Arundel	01589795	2.59	0.935	499.472
MD	Howard	01591400	59.31	1.273	68.681
MD	Howard	01594000	254.86	1.278	94.415
MD	Prince George's	01594526	232.32	1.214	63.976
MD	Allegany	01599000	187.52	1.180	26.943
PA	Fulton	01613050	27.71	1.248	29.862
MD	Washington	01617800	48.95	0.601	8.097
WV	Jefferson	01618100	41.18	0.766	3.624
VA	Augusta	01620500	44.81	1.563	50.503
VA	Rockingham	01621050	37.04	0.624	70.054
VA	Augusta	01626000	328.93	1.085	28.357
VA	Rockingham	01632000	543.90	1.077	62.645
VA	Rockingham	01632082	118.36	0.820	90.794
MD	Frederick	01637500	173.27	1.365	89.627
MD	Carroll	01639500	264.18	1.295	52.788
MD	Prince George's	01649500	188.55	1.181	73.961
DC	District of Columbia	01651800	8.50	2.096	310.140
MD	Prince George's	01653600	102.30	1.305	148.590
VA	Prince William	01658500	19.74	0.853	69.628
VA	Stafford	01660400	90.65	0.981	43.903
MD	Charles	01660920	206.94	1.141	79.566
MD	St. Mary's	01661050	47.91	0.908	93.556
MD	St. Mary's	01661500	62.16	1.045	91.481
VA	Hanover	01673550	66.04	0.962	22.708
VA	Spotsylvania	01673800	200.97	0.808	28.284
VA	Amherst	02024915	70.19	1.476	25.698
VA	Nelson	02027000	240.87	1.743	57.059
VA	Nelson	02028500	245.53	1.465	57.860
VA	Buckingham	02030500	585.34	0.732	16.329
VA	Greene	02032640	279.72	1.050	54.928
VA	Powhatan	02036500	58.02	0.691	21.043
VA	Buckingham	02038850	22.12	0.663	84.812
VA	Prince Edward	02039000	180.26	0.707	26.805

APPENDIX D

Total plan quality scores for 42 local jurisdictions

States	Local jurisdictions	Factual basis	Goals and objectives	Inter-organizational coordination	Policies, tools, and strategies	Impleme-ntation	Total plan score
MD	Allegany	3.61	4.55	5.00	3.28	1.67	**18.10**
	Anne Arundel	6.67	5.45	7.86	4.83	8.33	**33.14**
	Baltimore	6.11	8.18	5.71	4.31	5.83	**30.15**
	Carroll	7.22	4.55	7.86	3.45	5.00	**28.07**
	Charles	4.17	6.36	5.71	2.24	5.00	**23.49**
	Frederick	6.67	4.55	7.86	3.45	2.50	**25.02**
	Harford	2.78	4.55	6.43	1.55	5.83	**21.14**
	Howard	5.83	3.64	7.14	3.45	5.00	**25.06**
	Kent	6.39	3.64	5.00	2.24	1.67	**18.93**
	Prince George's	4.72	4.55	5.71	1.90	2.50	**19.38**
	Queen Anne's	6.11	4.55	3.57	3.97	5.00	**23.19**
	St. Mary's	5.56	6.36	5.71	5.34	5.00	**27.98**
	Washington	6.39	3.64	3.57	1.55	0.83	**15.98**
	Wicomico	5.83	8.18	5.71	4.31	2.50	**26.54**
PA	Bedford	6.67	4.55	5.00	3.45	5.83	**25.49**
	Blair	6.11	4.55	7.14	2.76	7.50	**28.06**
	Bradford	4.44	0.91	4.29	1.90	1.67	**13.20**
	Centre	5.83	2.73	4.29	2.24	1.67	**16.75**
	Cumberland	6.39	2.73	3.57	1.55	3.33	**17.57**
	Fulton	5.00	1.82	3.57	1.03	2.50	**13.92**
	Huntingdon	6.39	2.73	5.00	2.76	0.83	**17.71**
	Lycoming	6.11	4.55	5.71	2.07	3.33	**21.77**
	Mifflin	5.83	3.64	5.71	1.72	5.83	**22.74**
	Montour	3.33	5.45	4.29	2.59	5.83	**21.49**
	Perry	6.67	3.64	7.14	3.28	3.33	**24.06**
	Potter	6.11	5.45	5.71	2.41	5.83	**25.53**
	Schuylkill	5.83	3.64	5.00	1.90	5.83	**22.20**
	Tioga	6.39	6.36	5.00	2.07	3.33	**23.15**
VA	Amherst	3.61	5.45	5.00	2.76	3.33	**20.16**
	Augusta	7.78	6.36	7.14	4.31	7.50	**33.09**
	Buckingham	6.39	4.55	4.29	2.59	1.67	**19.47**
	Greene	4.72	6.36	3.57	2.24	2.50	**19.40**
	Hanover	4.17	4.55	4.29	1.55	2.50	**17.05**
	Nelson	5.56	3.64	2.14	1.21	0.83	**13.38**
	Powhatan	3.89	5.45	4.29	3.28	7.50	**24.41**
	Prince Edward	5.28	3.64	5.00	2.41	2.50	**18.83**
	Prince William	3.61	8.18	3.57	3.79	4.17	**23.32**
	Rockingham	5.00	4.55	4.29	2.07	6.67	**22.57**
	Spotsylvania	5.56	5.45	5.00	5.17	6.67	**27.85**

Table Continued

States	Local jurisdictions	Factual basis	Goals and objectives	Inter-organizational coordination	Policies, tools, and strategies	Impleme-ntation	Total plan score
VA	Stafford	6.67	4.55	5.71	4.48	6.67	**28.08**
WV	Jefferson	2.22	0.91	2.74	0.86	0.83	**7.56**
DC	Washington DC	4.17	6.36	7.86	3.45	8.33	**30.17**

APPENDIX E

Correlation Matrix

	Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
1	MAR	1															
2	MAPR	.409*	1														
3	Plan quality score	.195	.457*	1													
4	Plan year	-.045	.247*	.545*	1												
5	Number of planners	-.010	.267*	.185	-.119	1											
6	Consultant	-.116	-.267*	-.057	-.084	-.244*	1										
7	Impervious surface	.360*	.638*	.380*	.114	.426*	-.296*	1									
8	Natural cover	-.248*	-.540*	-.366*	-.249*	-.467*	.342*	-.730*	1								
9	Wetland	-.273*	-.219	.054	.213	.200	-.034	-.129	-.293*	1							
10	Slope	.262*	-.225	-.176	-.250*	-.398*	.192	-.367*	.698*	-.430*	1						
11	Shape	-.041	.407*	.086	.057	.047	-.094	.185	-.230*	-.083	-.169	1					
12	Precipitation	.562*	.454*	.286*	.145	.255*	-.482*	.372*	-.446*	-.042	-.215	.039	1				
13	Flood events	.410*	.501*	.258*	.009	.049	-.104	.395*	-.234*	-.217	.034	.332*	.220	1			
14	Natural drainage density	-.224	.076	.213	.204	-.177	.160	-.101	.251*	-.022	.229*	.007	-.157	-.013	1		
15	Floodplain	-.100	-.349*	-.242*	-.224	-.069	.021	.039	.176	-.094	.037	-.206	-.082	-.160	.122	1	
16	Soil	-.046	-.229*	.077	.158	.058	.106	-.085	-.067	.635*	.117	-.104	-.170	-.142	.035	-.160	1

Note: *: significant at p<.05

APPENDIX F

Sustainable Stormwater Management Plan Coding Form

Title of plan document: ____

Jurisdiction: ____

Organization that prepared plan document: ____________________________

Plan adopted/amended year: ______________________________________

Consultants involved: Y N

Name of coder: ____

Date coded: ____

Indicators	Code (Total)	Page # of Reference	Comments
1. Factual basis 0 = Not mentioned in plan 1 = Mentioned, but not detailed 2 = Mentioned and detailed M = Mapped C = Classified D = Described			
1.1 Resource inventory			
(1) Classification/description of vegetation/forests	M _____ D _____		
(2) Classification/description of soils	M _____ D _____		
(3) Inventory of local climate	D _____		
(4) Map or inventory of watersheds, wetlands and water resources	M _____ D _____		

Table Continued

Indicators	Code (Total)	Page # of Reference	Comments
1.2 Human impacts			
(5) Current population and population growth projection	M _____ D _____		
(6) Impervious surfaces area density and/or road density	D _____		
(7) Map or inventory of current and/or future land use	M _____ D _____		
(8) Map or inventory of main water pollution types and sources	M _____ D _____		
(9) Present and/or future needs of sewer/water infrastructure and services	M _____ D _____		
2. Goals and objectives 0 = Not presented 1 = Presented, but not detailed 1 = Presented			
(1) Goals are clearly specified			
(2) Presence of measurable objectives			
(3) Control/reduce stormwater runoff and/or flood			
(4) Improve water quality			
(5) Minimize impervious surfaces from development			
(6) Promote low impact development			
(7) Protect natural processes/functions (integrity of ecosystem)			
(8) Establish adequate funding for stormwater management			
(9) Maintenance/improvement of stormwater management (including water/sewer infrastructure) facilities			
(10) Encourage open spaces/recreation actions			
(11) Encourage public participation			
3. Inter-organizational coordination and cooperation 0 = Not mentioned in plan 1 = Mentioned, but not detailed 2 = Mentioned and detailed			

Table Continued

Indicators	Code (Total)	Page # of Reference	Comments
3.1 Beyond jurisdictional boundary			
Other jurisdictions/organizations/ stakeholders identified			
Coordination with other jurisdictions/ organizations/stakeholders identified			
Coordination with higher levels of governments (state/federal)			
Coordination with private sectors			
Integration with other plans/policies in the region			
3.2 Within jurisdictional boundary			
Coordination within jurisdiction specified			
Commitment of financial resources			
4. Policies, tools and strategies 0 = Not mentioned in plan 1 = Suggested in plan – vague commitment 2 = Mandatory in plan – firm commitment			
4.1 Structural tools			
Innovative stormwater management practices (BMPs / LID techniques / Green Infrastructure)			
Certified green building (LEED)			
Constructed wetlands			
4.2 General policies			
Consistency with other ordinances and regulations			
4.3 Regulatory tools			
Building codes to require water-efficient facilities (Green building)			
Development away from floodplains			
Land-use restriction near sensitive water bodies			
Innovative (Low impact development) design for new/re-developments			
Pesticides, herbicides, and synthetic fertilizers (pest control) regulations			
Restrictions on local vegetation and forest removal			
Setbacks and buffer zones			
Minimum pipe size / Pipe infrastructure			

Table Continued

Indicators	Code (Total)	Page # of Reference	Comments
Total Maximum Daily Load (TMDL)			
Urban service/growth boundaries			
Water-efficient landscaping (native)			
Water quantity and quality monitoring			
Erosion and sediment control			
4.4 Incentive tools			
Clustering development			
Density bonuses			
Stormwater utility fee (discounts)			
Stormwater impact fees			
Transfer of development rights			
4.5 Land acquisition tools			
Fee simple purchase (land and property acquisition)			
Conservation easements			
Openspace preservation			
Other land acquisition techniques			
4.6 Awareness tools			
Education/outreach program			
Training/technical assistance			
Maps of areas subject to flood hazards or stormwater runoff			
5. Implementation 0 = Not mentioned in plan 1 = Mentioned, but not detailed 2 = Mentioned and detailed			
Clear timeline for implementation			
Designation of responsibilities for actions			
Identification of financial and technical support			
Regular plan updates and assessments			
Monitoring of stormwater runoff impacts			
Highlighting stormwater sustainability			